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Operation IVY

PACIFIC PROVING GROUNDS

November 1952

Project 9.2

EFFECTS OF ATOMIC EXPLOSIONS ON THE IONOSPHERE

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No. 223 of 225 copies, Series A

Report to the Scientific Director

EFFECTS OF ATOMIC EXPLOSIONS ON THE IONOSPHERE

By

Fred B. Daniels
Arthur K. Harris
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Sponsoring Agency to:

Signal Corps Engineering Laboratories
Fort Monmouth, N. J.
August 1954

SECRET

ABSTRACT

During Operation Ivy an ionosphere recorder was operated at some distance from the test site. In addition, hf radio transmissions with paths nearly over the blast area were monitored.

A new phenomenon was observed in connection with the larger shot. It consisted of a sustained rise in the virtual height of the F2 layer, lasting more than 3 hr, and a simultaneous depression from normal values of the F2 critical frequency. These effects, although only relatively local in extent, are likened to those normally observed over large portions of the earth during magnetic storms. A possible physical explanation is propounded, based upon the hypothesis that much of the vertically propagated infrasonic energy produced by an explosion of this size is converted into heat in the lower portion of the F2 region.

Other effects on the ionosphere, observed during both shots, were similar to those recorded during earlier operations and corroborated previous theory attributing them to local changes of ion density caused by the sonic wave acting on the ionized layers.

No major disturbance to ionospheric communications was found. However, some attenuation of all radio waves passing through the D and E regions in the vicinity of the blast was observed, lasting only 15 min or thereabouts.

A period of marked ionospheric perturbation, starting about 2½ hr after the larger shot, was found in the regular vertical soundings at Guam. Possible indications of a similar effect appeared in Hawaiian and Okinawan ionosphere records at times corresponding to the greater distances. The apparent propagation velocity of the disturbance (13 km/min) and the period of the resultant ion-density variation (40 min) are near the middle of the ranges that have been observed for traveling disturbances of natural origin.

Experimental participation in Operation Castle was planned in order to determine whether or not local and distant ionospheric effects, such as those observed following the larger Ivy shot, are definitely associated with explosions of that order of magnitude.

ACKNOWLEDGMENTS

The assistance of the following individuals and organizations is gratefully acknowledged:

Fred Dickson and Harry F. Busch, Signal Plans and Operations Division, Office of the Chief Signal Officer, Washington, D. C., who assisted in planning, provided charts used in the data analysis, and supplied personnel for operation of the equipment.

Capt Anthony J. Kavka, Commanding Officer of the 9471st Technical Service Unit, U. S. Army Signal Corps, who assisted in preparation for the field work and trained the operating personnel.

Capt Albert Giroux, Commanding Officer of Mobile Section A, 9471st Technical Service Unit, U. S. Army Signal Corps, and enlisted men under his command, who operated the equipment in the field.

Airways and Air Communications Service, U. S. Air Force, which operated the various teletype circuits continuously during the test periods, made the data available for analysis, and supplied a teletype operator to Mobile Section A, 9471st Technical Service Unit.

Central Radio Propagation Laboratory, National Bureau of Standards, which made the ionosphere recorder available for this project and supplied additional ionospheric data.

Photographic Section of the Reproduction Branch, Signal Corps Engineering Laboratories, which was exceedingly cooperative in the preparation of the figures used in this report.

Walter S. McAfee, who furnished guidance and advice in the completion of this report; Henry A. Blake and Michael J. Scotto, who contributed valuable ideas in connection with traveling disturbances; and Alex N. Beichek and Arthur Eckstein, who rendered able assistance in the report preparation.

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CHAPTER 1

INTRODUCTION

1.1 OBJECTIVE

The objective of Project 9.2 was to obtain additional data on the effects of atomic explosions upon the ionosphere. From these data it was desired to obtain more complete explanations of phenomena previously observed and to correlate these and any new phenomena with the strength of the weapon. A further objective was to ascertain whether or not any serious disruption of normal ionospheric communication would be caused by larger weapons such as those detonated during Operation Ivy.

1.2 BACKGROUND

1.2.1 Vertical Incidence Ionosphere Soundings

During Operations Greenhouse, Buster, and Snapper, a C-3 Automatic Ionosphere Recorder was operated at locations near Ground Zero (GZ) at distances varying from 7 to 20 miles. The C-3 is a device which measures and records the virtual heights and the critical frequencies of the ionized regions of the upper atmosphere. This is accomplished by the transmission of pulses of rf covering a range of 1 to 25 Mc. The transmitted pulses are reflected from the various layers of the ionosphere, picked up by the receiver, and displayed as oscilloscope traces which show the virtual height of the reflections vs transmitted frequency. These traces are then photographed automatically. A more detailed discussion of the method and of the interpretation of the photographs may be found in Circular No. 462 of the National Bureau of Standards.[1]

The various effects observed in the ionosphere records for the three afore-mentioned operations (with the exception of the absorption effect of Greenhouse George shot discussed below) were ascribed in the Snapper report[2] to local changes in ion density caused directly or indirectly by the blast wave passing through the existing ionized layers.

After Greenhouse George shot, the normal E, F1, and F2 reflections gradually weakened, starting at G+4 min, and were completely absent at G+15 min, after which the F2 began to reappear slowly. All the layers did not return completely until $2\frac{1}{2}$ hr after the blast. There has been much speculation as to the possible explanation for a partial fadeout of such duration, unique to this particular explosion. A further study of these ionosphere records, in the light of results obtained during Operation Ivy, indicated that absorption or scattering in the lower regions of the ionosphere, due to the passage of the shock wave, was the probable cause of the absence of signal shortly after the shot. The fact that the E and F1 traces did not show a complete return to normal until $2\frac{1}{2}$ hr after the shot was probably due to the combination of typical solar-caused late-morning absorption and shot-caused absorption lasting longer for the lower frequency rays because of their greater tendency to be absorbed.

1.2.2 Interference to Ionospheric Radio Communications

During Charlie, Dog, and Easy shots of Operation Buster, the signal strength of short-range ionospheric radio transmissions (about 125 km) was recorded, the reflection point being almost directly above GZ. No serious impairment of the signal could be noted; however, rapid fading

commenced at about the time of arrival of the sonic wave and continued for about 15 min. The only observed diminution of signal strength followed the largest of the three shots.

During Operation Snapper, various pulse and c-w transmissions, with paths passing almost directly above GZ, were recorded and analyzed. On the basis of these data and theoretical considerations, it was inferred that disturbance to ionospheric radio propagation would exist for only a few minutes and then would be troublesome to voice communication only. The interference was attributed primarily to the occurrence of additional modes of propagation caused by reflection of the radio waves from the blast waves. The possibility of signal attenuation due to absorption, such as that which may have been the cause of the Greenhouse George fadeout, described in Sec. 1.2.1, was precluded by the location of the paths with respect to GZ and by the smaller size of the weapons.

1.2.3 Long-range Detection

In the report of Project 9.4, Operation Snapper,[2] it was concluded that the rapid fading observed in the recordings of c-w transmissions and ascribed to the blast might, under certain limitations, furnish a means of detecting an atomic explosion at great distances. It was further stated that, although such a scheme would probably work only during the hours when an E layer was present over the test site, monitoring a suitably located enemy transmitter could possibly furnish corroborative evidence as to the occurrence and location of an atomic explosion.

REFERENCES

1. Natl. Bur. Standards, U. S., Ionospheric Radio Propagation, Circ. No. 462, June 25, 1948.
2. F. B. Daniels and A. K. Harris, Effects of Atomic Explosions on the Ionosphere, Snapper Project 9.4 Report, WT-547, January, 1953.

CHAPTER 2

INSTRUMENTATION AND OPERATING PROCEDURE

2.1 OUTLINE OF EXPERIMENTS

2.1.1 Vertical Incidence Sweep Frequency Soundings

Vertical incidence sweep frequency soundings were recorded at Bikini Atoll, 360 km from GZ. Operation was continuous for several hours after each shot. In addition, normal ionosphere recordings, made by the Central Radio Propagation Laboratory (CRPL) stations at Guam and at Maui, T. H., were examined.

2.1.2 C-w Transmission

Recordings were made of the signal level of an unmodulated (c-w) radio signal, which was transmitted to Bikini Atoll from a circling airplane so located that the mid-point of the propagation path was directly above GZ, the entire path being about 720 km.

2.1.3 Communications Circuits

The transmitted and received radioteletype messages, sent in both directions over the Guam-Kwajalein and Guam-Honolulu normal communications circuits, were compared and analyzed to determine whether or not any interference existed. It was also planned to intercept the Guam-to-Kwajalein transmission at Bikini, record the signal strength, and compare the received text with that which was sent, but circumstances necessitated the changes described in Sec. 2.3.3.

2.1.4 Locations

The locations of the various ionosphere recorders and the c-w and teletype transmitters and receivers are shown in Fig. 2.1. Great-circle distances and paths are noted on this map, which is a standard Mercator projection.

2.2 INSTRUMENTATION

2.2.1 Ionosphere Soundings

A type AN-CPQ-7A Ionosphere Recorder (model C-3) was installed on Bikini Island, Bikini Atoll, and a standard single-strand vertical delta antenna, 65 ft high, was erected. The 16- and 35-mm photographic records of the traces appearing on the oscilloscopes of the recorder were developed on location. The existing ionosphere recorders at Guam and Maui were operated by CRPL in their normal manner.

2.2.2 C-w Transmission

A type ART-13 transmitter was located in a Navy P2Y patrol bomber during both tests. For Mike shot, the transmitter was operating at 90 watts input with 2.4 rf amp into a 52-ft fixed antenna. The plane maintained an altitude of 1100 ft. For King shot, the input was 95

watts and the rf current into a 125-ft trailing wire antenna was 1.25 amp. The plane remained at a 1000-ft elevation throughout this test. For both runs, reception was on Eninman Island, Bikini, using a 40-ft-high center-fed half-wave doublet antenna, resonant to 5600 kc, having a bearing of 270°. An Esterline-Angus recorder was used to register the signal level.

2.2.3 Radioteletype

The standard teletype circuits employed during the tests used their customary transmitters and receivers. A radio receiver type R-336/GRC-26 was operated at Eninman Island,

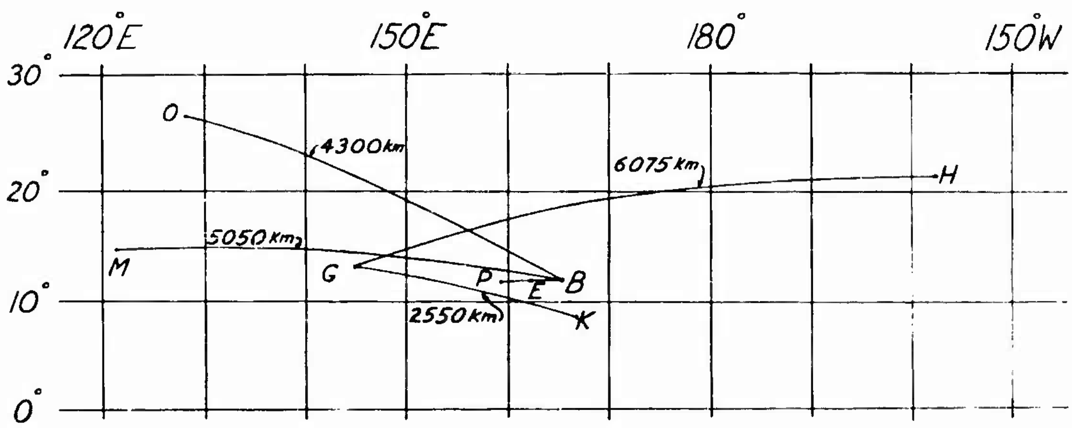

Fig. 2.1—Great-circle transmission paths and distances showing relationship of the paths to GZ, Eniwetok (B, Bikini; P, Airplane; G, Guam; K, Kwajalein; H, Honolulu; O, Okinawa; M, Manila; and E, Eniwetok).

Bikini, to monitor existing circuits. The received signal strength was recorded on an Esterline-Angus meter. Two center-fed half-wave doublet antennas, resonant to 8935 kc and elevated 40 ft above the ground, were used in dual-diversity reception. They were located one behind the other, spaced approximately 60 ft apart, and had a bearing of 270°. For King shot, the antennas were shortened to make them resonant to 9950 kc.

2.3 OPERATING PROCEDURE

H hour for Mike shot was 0715 local time on 1 November, corresponding to 1915 hours, 31 October, at Greenwich. King shot occurred at 1130 hours, 16 November, or 2330 hours GMT, 15 November.

2.3.1 Ionosphere Recorders

To determine general ionospheric conditions, the Ionosphere Recorder was maintained on normal operation on nonshot days (i.e., one sweep every $\frac{1}{4}$ hr plus one sweep at 1 min past the hour). From 23 October until 5 November, the equipment was in operation for several hours each morning (roughly 0300 to 1100 hours local time), with 24-hr operation the day preceding and the day following Mike day. On Mike day itself, operation was continuous (one sweep every $7\frac{1}{2}$ sec) from 0719 until 0852 hours. From 0852 to 1205 there was one sweep per minute, from 1205 to 1445 one sweep every 5 min, and thence normal operation ensued. From 11 until 19 November the recorder was in normal operation 24 hr a day. On King day, continuous operation began at 1134 hours and continued for 1 hr. At 1234, a program of one sweep per minute was started and was continued until 1430, when normal operation was reinstituted. The recorder

was turned off several minutes before and remained off until several minutes after each shot in order to prevent interference with other measurements being made at that time.

Although continuous operation of the CRPL recorders at Guam and Maui had been planned for shot days, only normal operation was possible because of conflict with other experiments. Copies of the film, as well as hourly virtual height and frequency scalings for several days before and after each shot, were received and studied.

2.3.2 C-w Transmission

On both shot days, the bomber which carried the transmitter flew a clockwise circuit with a north to south straightaway distance of approximately $12\frac{1}{2}$ land miles, making banked turns at the north and south ends, the mean distance from GZ being about 360 km (~200 miles). The flight schedule was predetermined so as to have the plane in the north-south straightaway from H+4 to 9 min and from H+12 to 15 min. These times were specifically selected because results of previous operations indicated that effects might be observable then. With the airplane flying straight and level in a direction perpendicular to the radio path, the following variables would remain fairly constant: the relation between the antenna radiation direction and the airplane, the path length, and the antenna height.

Although no two-way radio contact was made prior to Mike shot, it was determined afterward that the transmitted signal was indeed received starting a few minutes before H hour. On King day, reception of the transmitted signal began as soon as contact was attempted, at H−1 hr. In each case, a frequency of 5600 kc was used, and transmission continued until 2 hr past shot time. For identification purposes, the c-w signal was keyed, using breaks 1 sec long. For Mike, there were two breaks going into and coming out of each south turn, and there was one break going into and coming out of each north turn. The north and south breaks were reversed for King shot.

At the receiving end, an Esterline-Angus recorder was used to measure the signal strength. It was operated at a speed of 6 in./min.

2.3.3 Radioteletype

It was planned to intercept the standard Guam-to-Kwajalein teletype transmission at Bikini and record its signal level. Just before H hour on Mike day, as well as at the same time of day on Mike−1 day and Mike+1 day, attempts were made to receive this signal on all its assigned frequencies (8935, 12,940, and 17,470 kc), but they met with no success. Instead, a 7810-kc signal was received from H−30 min until H+130 min, which was later determined to be Okinawa transmitting to Kwajalein.

For King day, instructions were given to substitute the interception at Bikini of the Eniwetok radioteletype station ABE on 9950 kc in place of the Guam transmission. However, ABE could not be received, and therefore it was decided to copy station DZM25 at Manila, sending to Kwajalein on 9947 kc, from H−30 min until H+165 min.

Transmitted and received "hard copy" for the following standard circuits, which were in continuous operation on Mike day during the listed times, was received and analyzed:

Guam to Kwajalein, 8935 kc, from H−75 to +285 min.
Kwajalein to Guam, 9205 kc, from H−75 to +265 min.
Guam to Honolulu, 11,610 kc and also an unreported frequency, from H−75 to +284 min.
Honolulu to Guam, 10,435 kc, from H−75 to +234 min.

Similarly, on King day, hard copy was received for the following circuits:

Guam to Kwajalein, frequency unreported, from H−30 to +240 min.
Kwajalein to Guam, 12,285 kc, from H−30 to +240 min.
Guam to Honolulu, 15,545 kc, from H−30 to +210 min.
Honolulu to Guam, 14,820 kc, from H−30 to +210 min.

Also available was hard copy for the Guam-to-Kwajalein and Honolulu-to-Guam circuits

for a 3-hr period in the vicinity of noon of King −1 day. This occurred because the firing was delayed and the operators were not notified.

Received hard copy was compared with transmitted texts for accuracy whenever the latter were available. In the few instances where no transmitted hard copy was obtained, it was possible to infer what was sent since, in general, test tapes were used. As a basis for analysis, it was decided to use the number of "hits," which "can be considered an evaluation of the ability of the communications system used to convey the signaling code."[1] A hit refers to "faulty operation of the receiving teletypewriter due to the distortion beyond a tolerable value, of a signal impulse received by the teletypewriter."[1] In order to estimate the number of hits, the standard practice was adopted of counting a hit whenever an error appeared in the received message for two or more consecutive characters or signals.

The Esterline-Angus meter used to record the signal strength of the stations intercepted at Bikini was operated at a speed of 6 in./min. At the receiving end of the normal communications circuits, the signal level was noted on the hard copy at 5-min intervals.

REFERENCE

1. A. Silberman, Analysis of Page-printed Teletype Test Copy, Signal Corps Engineering Laboratories, Tech. Memo. No. M-1474, November 1952.

CHAPTER 3

RESULTS AND ANALYSIS OF DATA

3.1 IONOSPHERE SOUNDINGS

Regular multifrequency sweep records obtained at Guam and at Maui were inspected. Although no effect on the ionosphere was found at first, re-examination of oscillograms taken at Guam during Mike shot revealed a marked perturbation of the ionosphere. Because it had started after the expected arrival time of the compressional wave initiated by the explosion, this effect was originally overlooked. A full description, with illustrations, is presented in Sec. 3.4.

Examination of the ionosphere recordings obtained by project personnel at Bikini Atoll, 360 km from GZ, indicated that the Mike records were more complex than the King records. Hence the latter were analyzed first, and the results are presented in the same order, the reverse of the temporal sequence, in Secs. 3.1.1 and 3.1.2.

3.1.1 King Shot Data at Bikini

Twelve representative sweep frequency records have been selected to show the normal ionospheric picture and the various effects of King shot upon it. They are presented in Figs. 3.1 to 3.3, each arranged to be read from top to bottom, starting at the left, with the elapsed time from zero indicated in minutes and seconds. Unfortunately, the traces are not clear because the camera was out of focus. Also, many pictures suffer somewhat from results of the difficulties of storing film in a tropical climate and of developing it there with an inadequate supply of cool water.

(a) Pre-effect Conditions. There is no observable effect which can be attributed to King shot until 14 min 30 sec after zero. The first picture of Fig. 3.1, at 11 min, is a typical pre-effect record. The E-layer trace at a virtual height of 100 km was absorbed up to a frequency of 2.5 Mc, in lower regions of the ionosphere, since the time was near local noon. Both the ordinary and extraordinary F1-layer traces are clearly visible between 3.5 and 5 Mc, although their upper ends were occluded intermittently in other pictures not shown. A stratification in the lower portion of the F2 layer, which had been present for about $^3\!/_4$ hr, is evident near 5 Mc.

The electron-density distribution curve (Fig. 3.4) was calculated from the pre-effect picture at 11 min (see Fig. 3.1). The method of Appleton and Beynon[1] was used for the E-layer portion of the curve, and that of Manning[2] was used for the F1 and F2 layers. This curve, in addition to showing the computed electron-density variation with height, also gives, by means of a second set of abscissas, the true height of reflection (calculated with effects of the earth's magnetic field neglected) of a normally incident wave of frequency f_0 Mc. This frequency corresponds to an electron density of N free electrons per cubic centimeter according to the classical ionosphere equation:

$$f_0^2 = \frac{Ne^2c^2}{\pi m} = \frac{N}{1.24 \times 10^4} \tag{3.1}$$

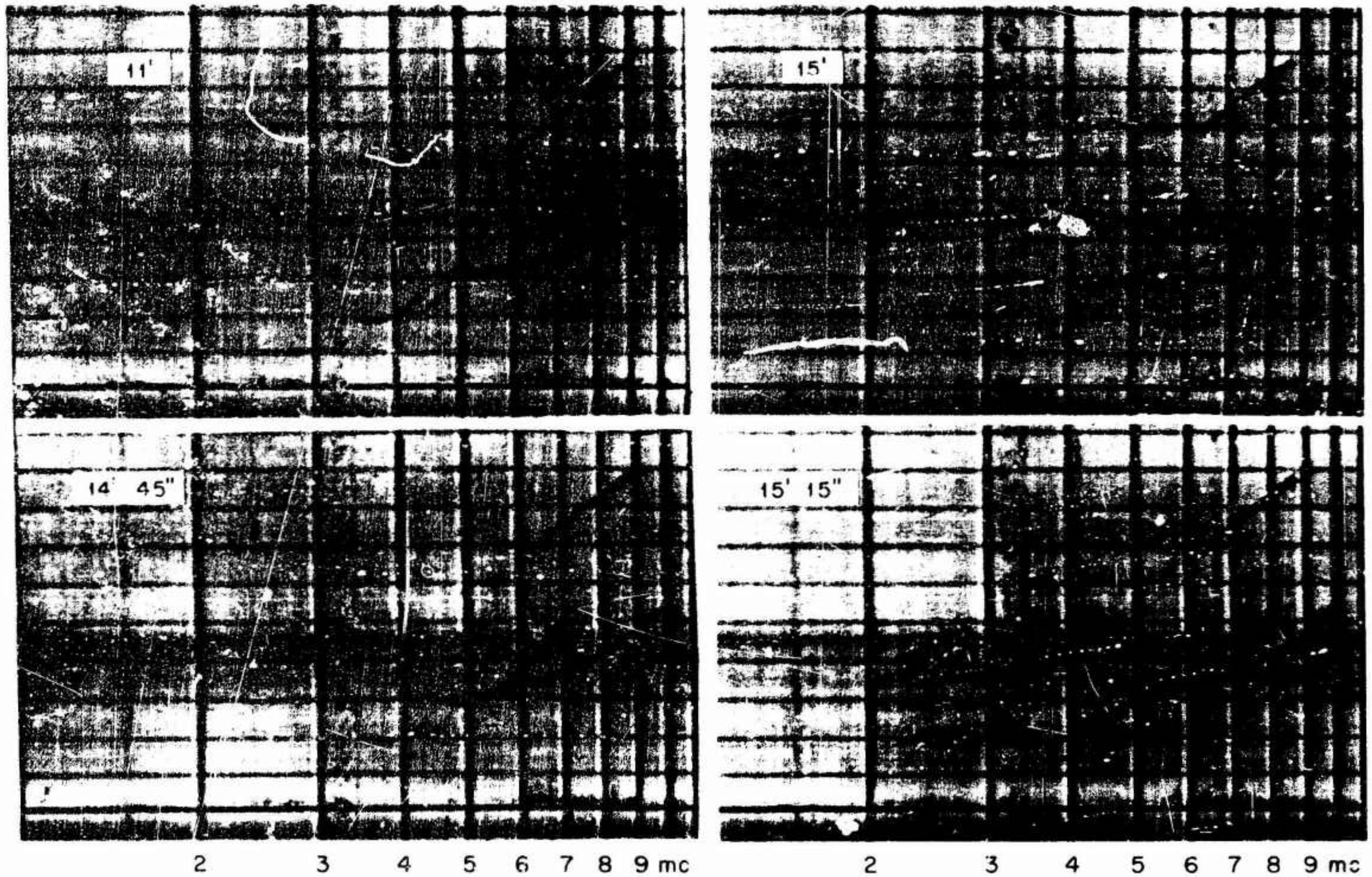

Fig. 3.1 —Representative ionosphere records at Bikini (King shot), from H + 11 min to H + 15 min 15 sec. (Horizontal lines show 100-km height increments above ground level, the heavy line.)

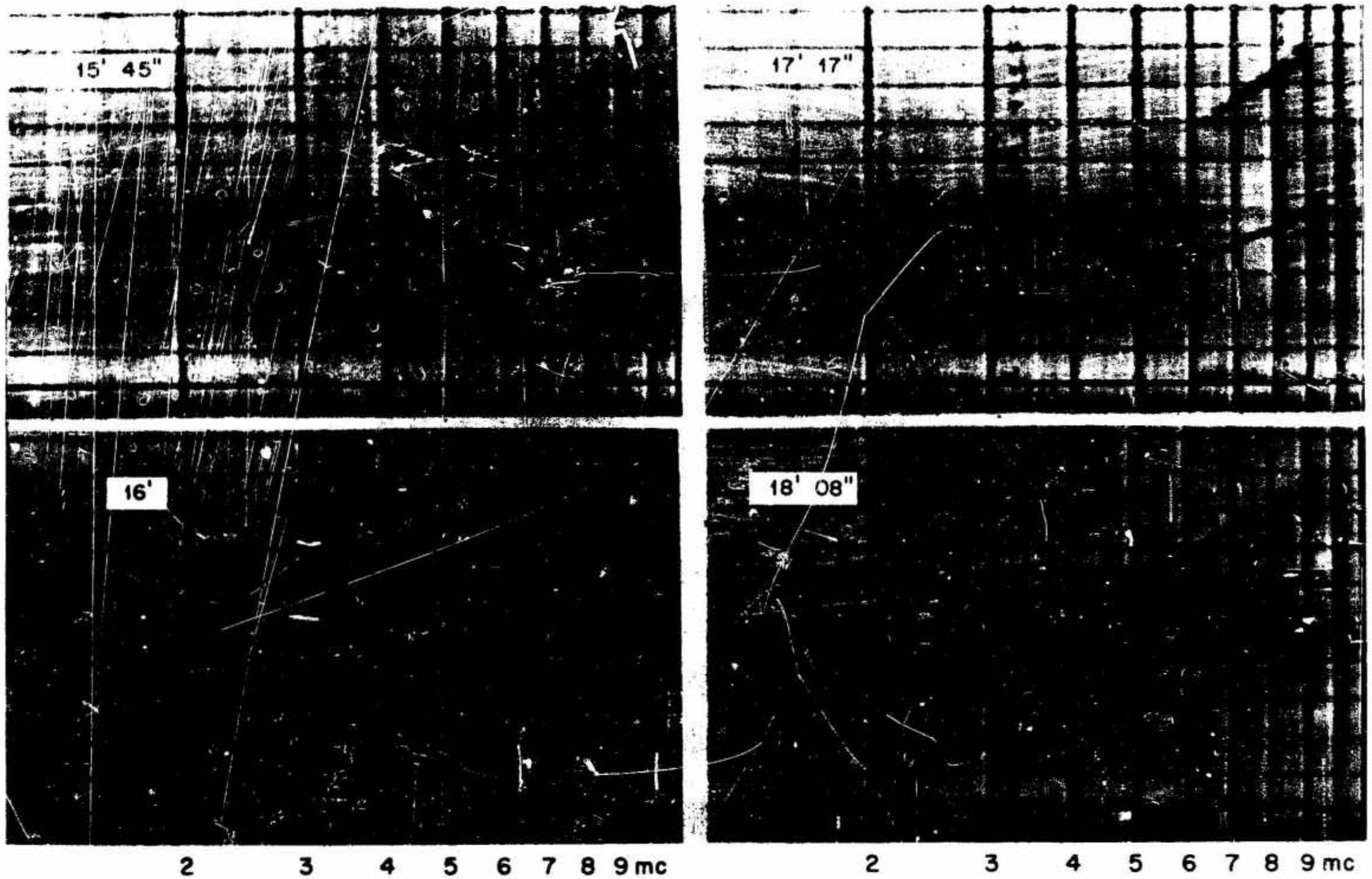

Fig. 3.2—Representative ionosphere records at Bikini (King shot), from H + 15 min 45 sec to H + 18 min 8 sec. (Horizontal lines show 100-km height increments above ground level, the heavy line.)

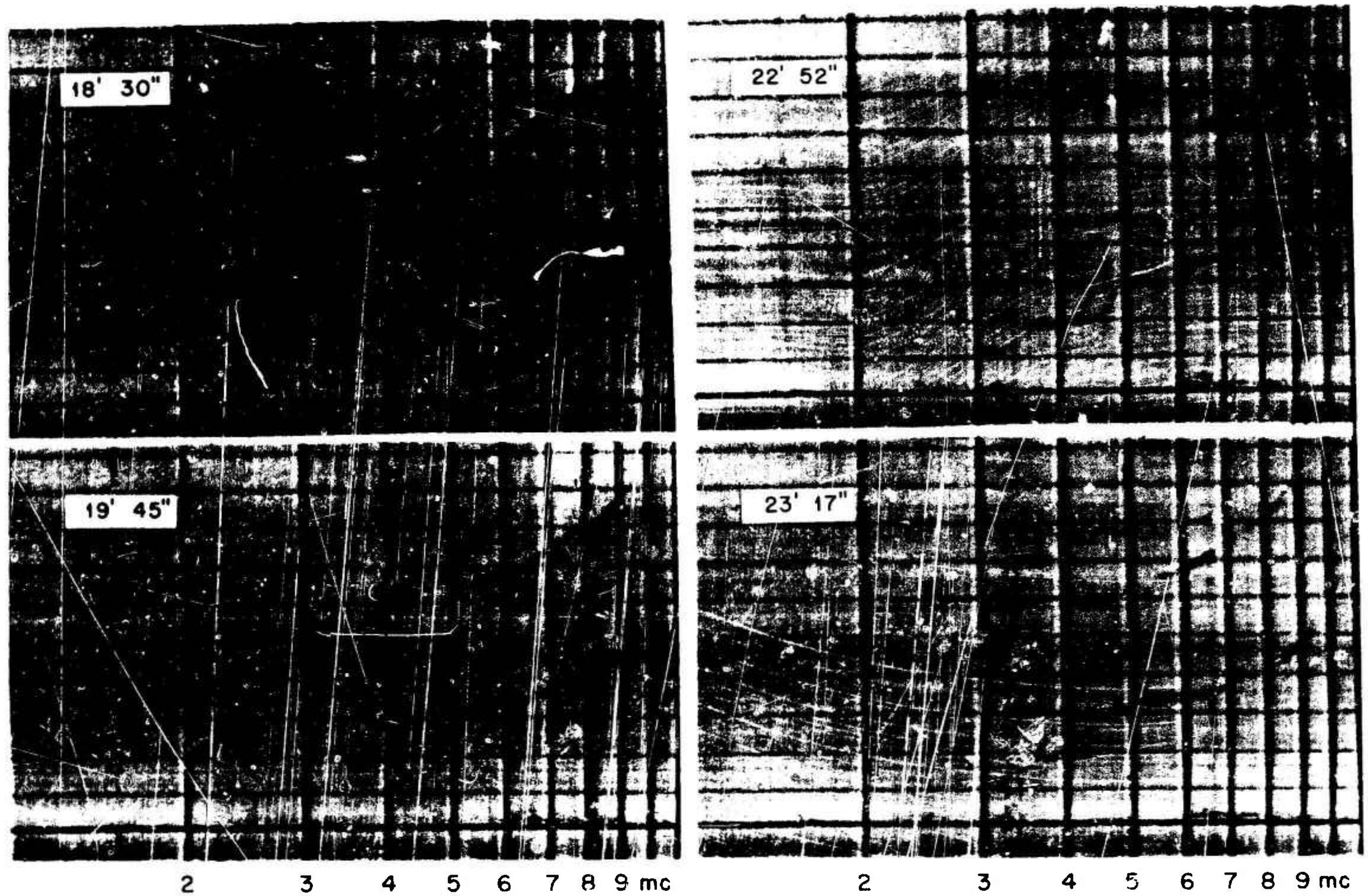

Fig. 3.3—Representative ionosphere records at Bikini (King shot), from H + 18 min 30 sec to H + 23 min 17 sec. (Horizontal lines show 100-km height increments above ground level, the heavy line.)

where e is electronic charge (1.60×10^{-20} emu), m is electronic mass (9×10^{-28} g), and c is free space velocity (3×10^{10} cm/sec). Data from this curve (Fig. 3.4) were used in the interpretation of later ionosphere records which show effects of the blast.

(b) Effects in the E Region. From 14 min 30 sec to 16 min 37 sec, there appeared a series of short straight traces in the E region, steadily decreasing in apparent height from 154 to 125 km. Figure 3.5 is a composite graph of this phenomenon. (Actual records of some of the more distinct traces of this series are seen in the last three pictures of Fig. 3.1 and the first two of Fig. 3.2.) The adjective "apparent" has been used advisedly to describe the height, in place

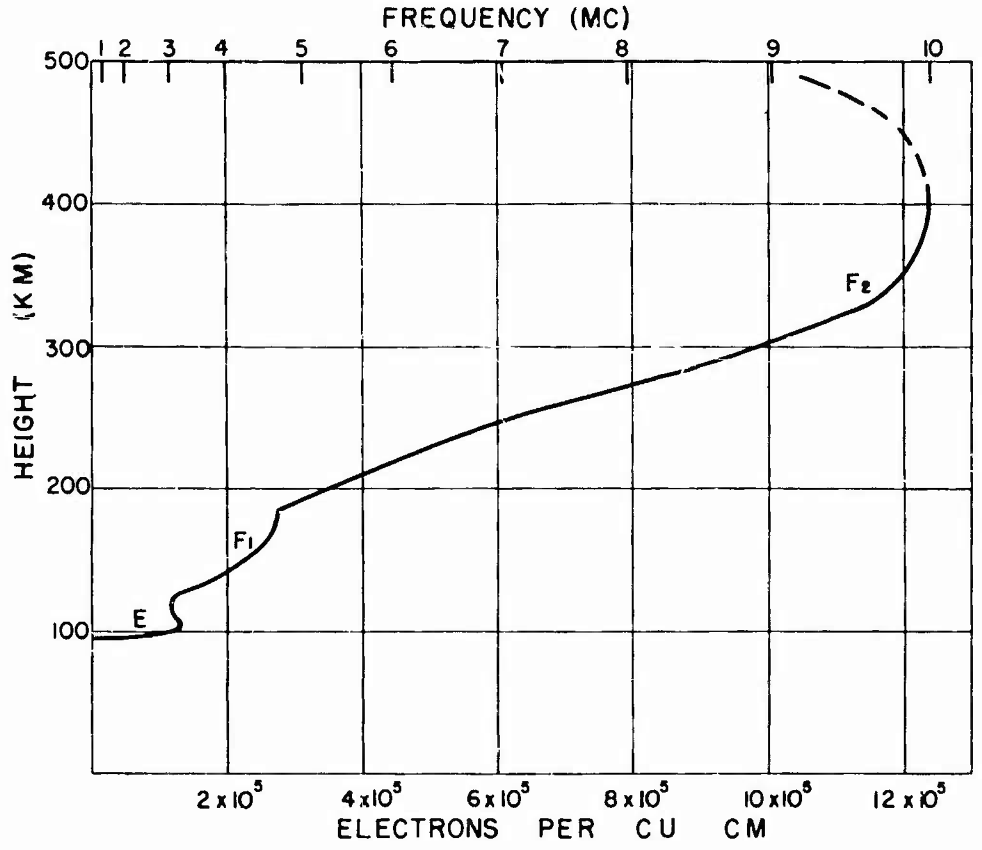

Fig. 3.4—Calculated electron-density distribution and critical frequencies, King day, prior to arrival of shock wave.

of the usual "virtual height," since those traces will be shown to have been oblique reflections, at a height of about 96 to 100 km, from a disturbance in the E region moving toward the ionosphere recorder.

It is to be noted that, although the C-3 is known as a "vertical incidence recorder," the antenna radiation pattern is broad enough to allow the transmission and reception of oblique rays without undue reduction of signal strength. Such rays would appear on the oscilloscope as traces above the normal E-layer height owing to their greater path length.

In order to relate the observed E-layer effect, as well as certain other effects which occurred in the F region, to the sonic wave emanating from the blast, a group of theoretical sonic-ray paths was plotted in Fig. 3.6 (assuming plane earth and horizontally stratified atmosphere), based upon the atmospheric data adopted by the Upper Atmosphere Rocket Research Panel.[3] Successive wave fronts at 1-min intervals were then located starting at 14.5 min.

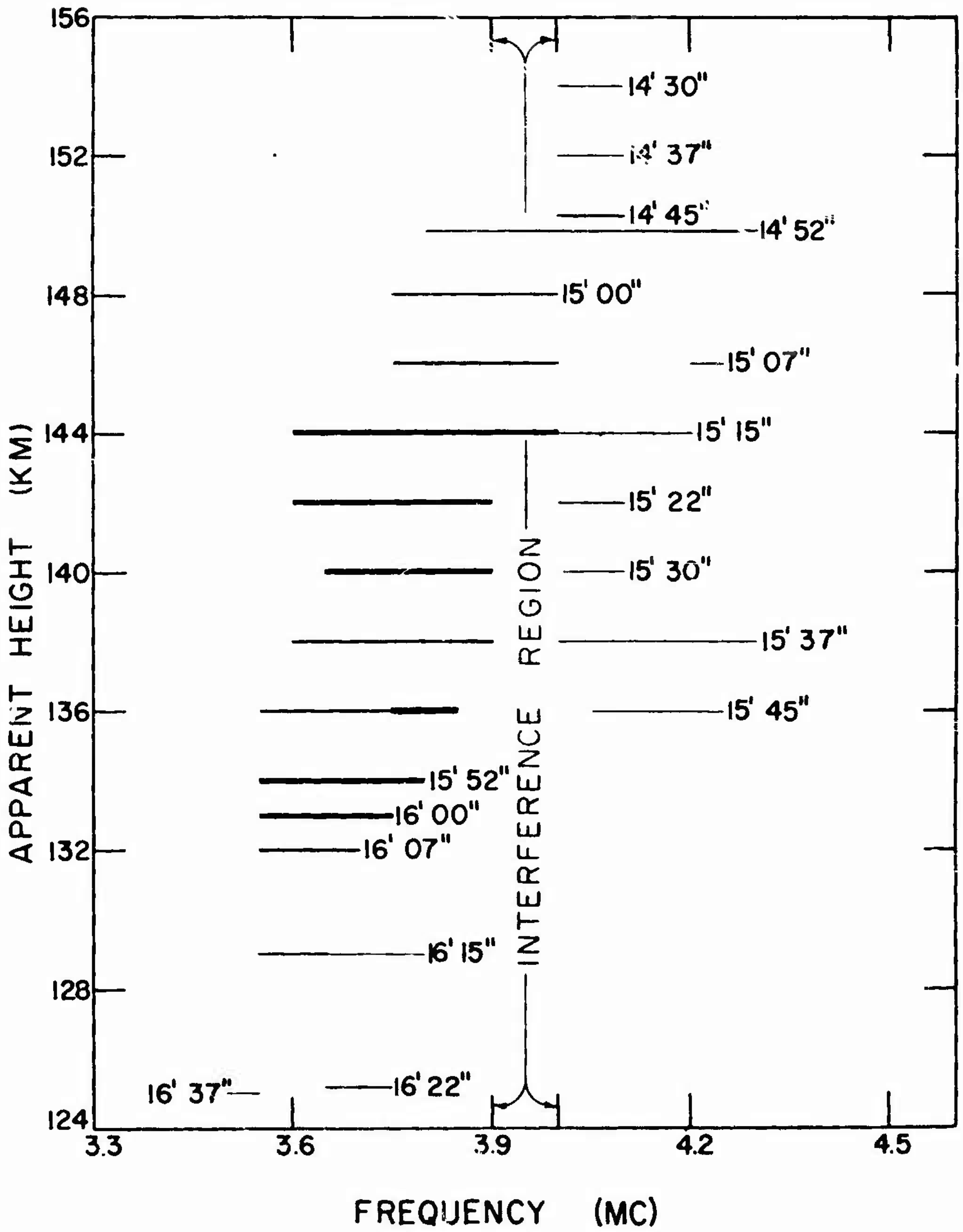

Fig. 3.5—Effect in E region, King day. (The descending tracings on the ionosphere recorder at Bikini are plotted compositely, height vs frequency range, with time from H hour listed adjacent to each. Thickness of line indicates relative strength of received signal.)

Portions of these wave fronts are repeated in Fig. 3.7, with some modification above a height of 110 km which need not be of concern at this point in connection with E-layer reflections.

In the lower portion of Fig. 3.7, oblique rays at four selected post-shot times are shown. Upon entering the E region they are refracted until they are normal to the sonic front. The rays are then reflected and returned to the C-3 by the same path. As the front proceeded toward the recorder, the path length became progressively shorter, and hence the apparent height decreased, which is precisely what was observed and is depicted in Fig. 3.5. As can be seen by

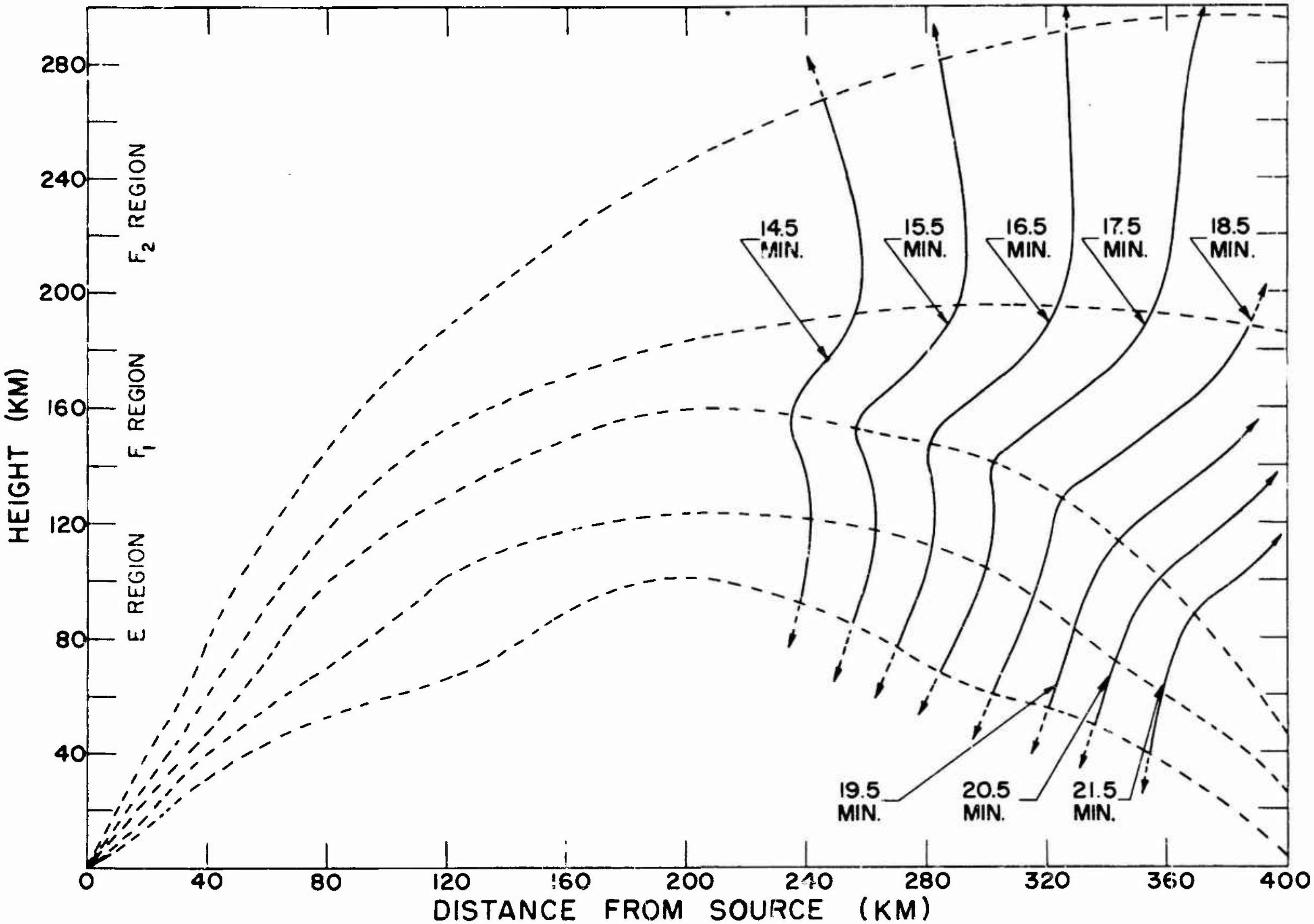

Fig. 3.6 — Passage of a theoretical sonic-wave front through a standard upper atmosphere. (Dashed lines are sonic-ray paths for several departure angles. Times are from zero.)

12

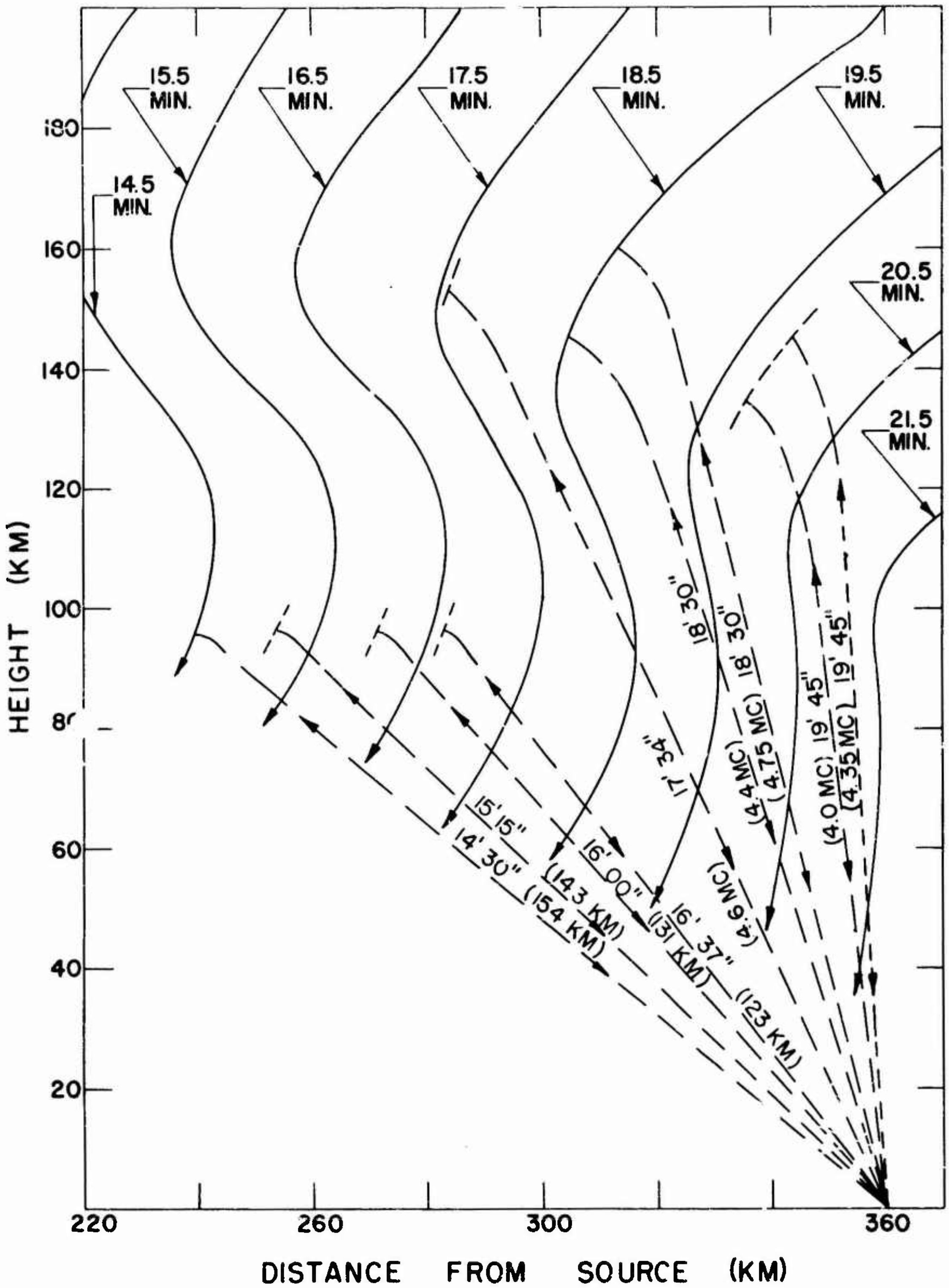

Fig. 3.7—Reflection, at the theoretical sonic-wave front in the E and F1 regions, of oblique radio rays emanating from the ionosphere recorder, King day. (The short dashed lines represent the front at times from H hour corresponding to the plotted radio rays.)

a comparison of Fig. 3.5 with Fig. 3.7, the four representative oblique E-layer reflections have distances equal (within 2 km) to the apparent heights at corresponding times.

The oblique reflections observed in the E region had definite upper and lower frequency limits. Figure 3.8 is a pictorialization of the probable ionospheric conditions causing this effect. It shows the effect, on the normally horizontal isoionic surfaces, of a single condensation and rarefaction of a hypothetical sonic wave with a steep front, having an average period of about 12 sec. The lines of equal ion density are denoted by their respective critical frequencies (see Eq. 3.1).

The well-known secant law for plane earth and horizontally stratified ionosphere states that if a certain frequency f_0 is returned by a given ion density at vertical incidence, then the same ion density will, at an angle i incident to the layer, return a frequency sec i times as great. Using simple trigonometric transformation, the above statement may be written in the form

$$f_0 = f \sin \alpha \tag{3.2}$$

which indicates that an oblique ray of frequency f leaving the earth at an angle α will rise to the same level in the ionosphere as a vertical ray of frequency f sin α. This is the level where the electron density corresponds to f_0 as defined in Eq. 3.1. By thus being able to determine the maximum height of oblique rays and also knowing their travel time and the computed position of the shock front, it was possible to estimate the various reflection points and to construct the rays of Fig. 3.8.

A ray reflected at lower than normal height indicates an increase in ion density. Since the ion density needed to reflect normally incident waves of a given frequency is known (Eq. 3.1), the increase in electron density caused by the condensation phase of the compressional wave was approximated, and the sonic distortion of the isoionic surfaces was drawn.

The slope of the shock front in Fig. 3.8 was taken from the fronts plotted in Fig. 3.6 at the time of zero +15 min 15 sec. Figure 3.5 shows that the main signal returned at this time is between the frequencies of 3.6 and 4 Mc. Thus Fig. 3.8 shows rays in this frequency range being refracted upon entering the E region until they reach the shock front perpendicular to it, then being reflected, and returning to the recorder. As shown, rays of no other frequencies were reflected directly back to the recorder. The 4.5-Mc ray which reached the shock front perpendicular to it did not meet sufficient ion density to be returned. The 3-Mc ray in the lower portion of the figure and also two other 4.5-Mc rays at slightly higher angles are shown to be refracted in a manner leaving them oblique to the front; thus they were reflected in directions other than back along the incident path.

As the sonic wave moved toward the recorder, lower frequency rays which heretofore had been obliquely reflected before reaching the shock front began to be normally incident to it and returned to the recorder. Thus they appeared as traces on the oscilloscope. At the same time, higher frequencies which had been returned by reflection at the region of increased ion density began disappearing from the trace because their rays which reached the front perpendicularly did not encounter sufficient ion density to reflect them. This was due to attenuation of the sonic wave and impingement of the radio wave on the sonic front at a lower height, both of which result in lower ion density in the reflection area.

The weak higher frequency portions of the signal returned from the disturbed E region (see Fig. 3.5) appear to be similar to sporadic E and can best be explained by reference to the scattering theory developed by Booker.[4] Since the E region has been shown by Ratcliffe[5] to have a fine structure even under quiet conditions, the Booker equation for the scattering cross section per unit volume can be applied:

$$\sigma = \left[\left(\frac{\Delta N}{N}\right)^2\right]_{av.} \left(\frac{f_0}{f}\right)^4 \frac{1}{32\pi l \sin^4 \theta/2} \tag{3.3}$$

where $[(\Delta N/N)^2]_{av.}$ is the mean square fractional variation in electron density from average, l is the scale of fine structure, and θ is the angle between the direction of incidence and the

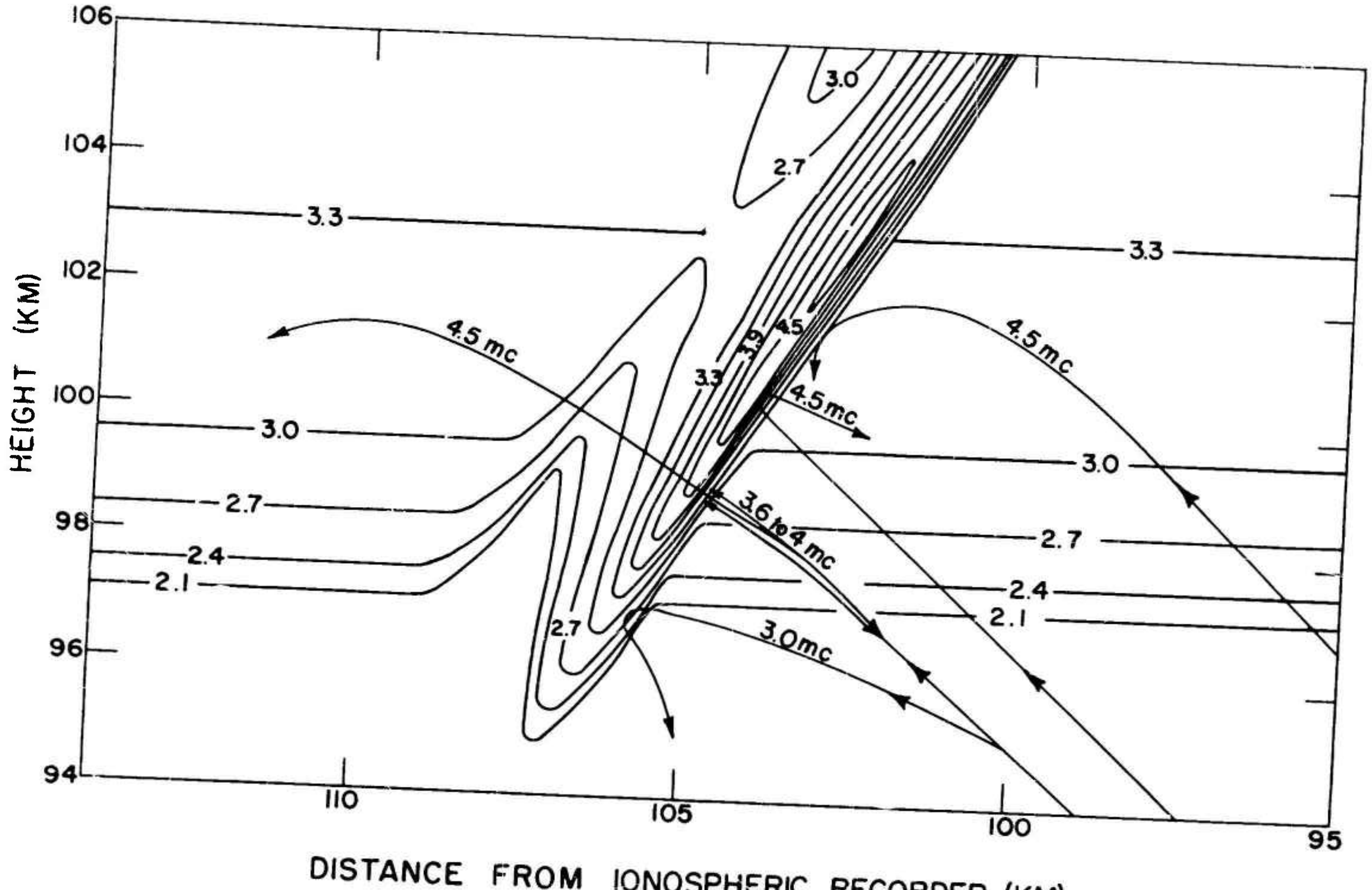

Fig. 3.8—Effect of a shock front on the E layer, showing a possible distortion of isoionic surfaces. (These surfaces are labeled with the vertical incidence frequency corresponding to the electron density. The layer critical frequency is 3.3 Mc. Various oblique rays from the ionosphere recorder are shown entering the layer and either being returned to the recorder, reflected in other directions, or penetrating the layer. Numerical values are based on King-shot data.)

direction of scatter. The passage of the sonic wave through the E region would have no significant effect upon any of the parameters of Eq. 3.3 except to increase f_0, the critical frequency of the volume concerned. Since the fourth power is involved, even a relatively small increase in frequency (or ion density, which is proportional to the square of the frequency) would greatly increase the scattering power of the volume. Thus these weaker portions of the trace appear to be scattered returns from the disturbed region in the E layer, obeying Eq. 3.3. The upper frequency limit of these returns is determined by the value of σ corresponding to the minimum signal detectable by the equipment.

(c) Effects in the F1 Region. An effect in the F1 layer which seemed similar to the series of oblique returns from the E region is seen in the pictures at 18′08″, 18′30″, and 19′45″ (see Figs. 3.2 and 3.3). However, unlike the straight line of the E-layer effect, the trace was curved owing to the fact that it appeared only near the critical frequency of a relatively deep layer; it was also peaked, probably because of the stratification existing in the F1 layer prior to the shot effect. A distinct trace, having a higher critical frequency than the normal F1 return, appeared at 17′34″. At first only a small band of frequencies was seen, but by 18′08″ (see Fig. 3.2) it had widened to include about 0.4 Mc from 4.35 to 4.75 Mc at an apparent height of 330 to 355 km. The apparent height of the highest portion decreased slowly for about another minute, during which time there was a fairly strong oblique echo (see the 18′30″ picture of Fig. 3.3). It then faded out, disappeared completely for half a minute, and reappeared at 19′45″ (see Fig. 3.3) at lower frequencies (4 to 4.35 Mc).

A partial representation of this effect is diagrammed in Fig. 3.7 by the rays from 17′34″ to 19′45″. The returns are shown to be from a sonic wave in the F1 region advancing toward the recorder. Each of the rays is refracted until reaching the front and is then reflected along the same path to the C-3. The widening of the band of returned frequencies is also represented by the two rays at the limiting frequencies at 18′30″. It can also be seen why, at 19′45″, the difference in height between the oblique and normal returns is slight, with the wave almost overhead in the F1 region.

It should be noted that, to make the actual returns coincide with those from theoretically computed sound waves, it was necessary to delay the wave front of Fig. 3.7 by 1 min in the F1 region. This might be accounted for physically by high ionospheric winds which were not taken into consideration in the original computation of the theoretical sound waves.

(d) Effects in the F2 Region. Starting at +15 min and continuing for $3^1/_2$ min, an additional trace appeared just below and to the right of the normal two-hop F2. At first the effect occurred only near the critical frequency and was obscure, but by 15′45″ the frequency range had increased, and both the normal and abnormal two-hop traces had become distinct (see Fig. 3.2 and 18′30″ of Fig. 3.3). Figure 3.9 shows the path which the abnormal return may have followed. It depicts slightly oblique rays, near the F2-layer critical frequency, refracted downward and headed toward the ground some distance from the transmitter. On their downward passage the rays are shown being refracted by a compressional wave acting on the ionized layer, so that they emerge from the ionosphere perpendicularly incident upon the earth. They are then reflected back toward the ionosphere and retrace their path to the recorder. In passage, the distance between the apex of the path and the ground is covered four times, and the trace appears upon the oscilloscope adjacent to the two-hop F2. The strong abnormal trace which was seen may have been due to focusing of many rays into vertical paths like the two shown in Fig. 3.9.

In the pictures the two-hop F2 appears below and to the right of the normal two-hop F2. This occurred despite the oblique path's greater length. It may be accounted for by the fact that the critical frequency of an obliquely reflected wave is higher than the normal incidence critical frequency by a factor of the secant of the angle of incidence. Then, at any particular frequency, the apparent height of the vertical return would be greater than that of the oblique due to greater retardation of the former, since the frequency was closer to the vertical critical frequency.

It is entirely possible that the compressional wave did not cause sufficient electron-density change in the F2 region to cause the refraction into the vertical direction as shown in Fig. 3.9

and that the oblique F2 rays would reach the sonic front in the F1 region rather than in the F2 region. This would not invalidate the preceding analysis since the rays would be bent perpendicular to the earth, but in the F1 region instead of the F2, and the rest of the analysis would follow. As an illustration, refer to Fig. 3.9 and assume the sonic front to be at about $^2/_3$ of the height shown, with the same sort of refraction and reflection taking place.

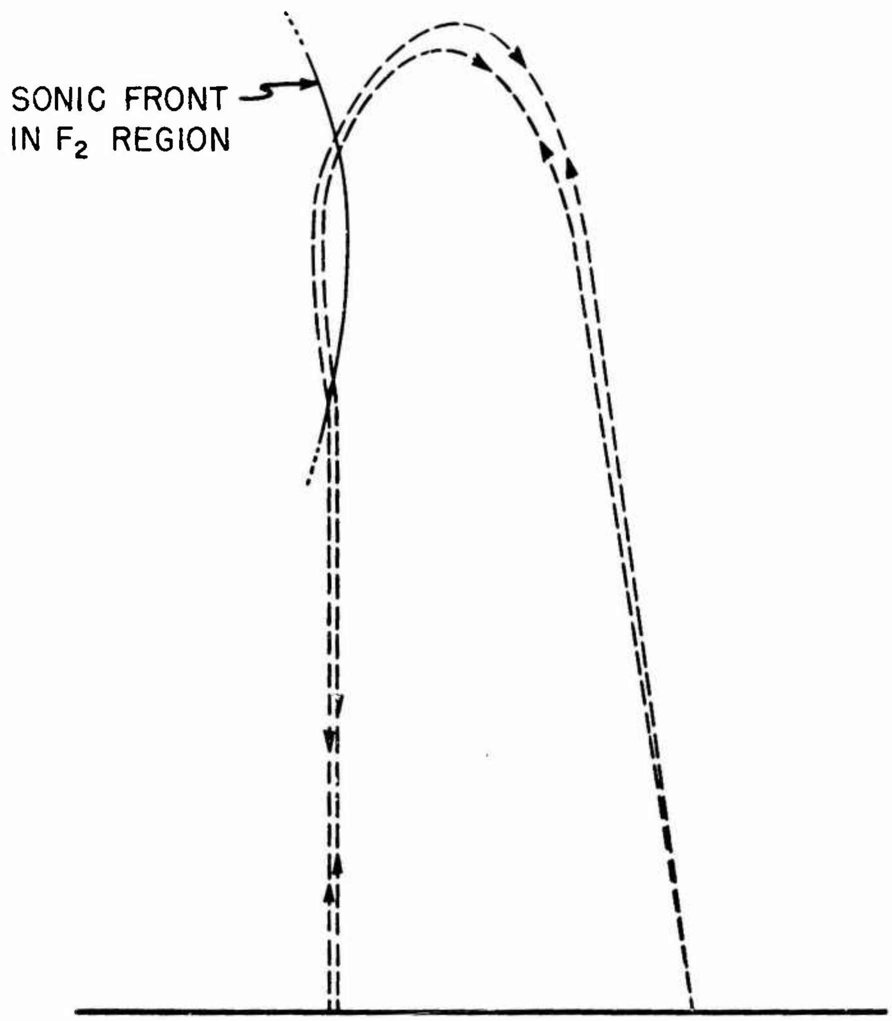

Fig. 3.9—Possible oblique two-hop F2 ray path.

(e) Absorption Effects. As the compressional front passed overhead, portions of the trace were occluded, probably owing to absorption (or scattering) in the lower ionized regions. For example, during three consecutive sweep recordings starting at +20 min (pictures not included in this report), portions of the normal F1 trace were missing. Then, 23 sec later, and lasting two sweeps, only the trace formerly identified as oblique F1 was seen, being recognizable by its higher critical frequency. By 20′45″ the normal F1 trace had returned. Examination of Fig. 3.6 reveals that during this period the calculated sonic front was in the E region and therefore was the likely cause of the occlusions.

The last two pictures of Fig. 3.3 are included to show the various forms of absorption which appeared at a later time. They may very well have been due to later arrivals of the

compressional wave affecting the D region. A complete theory for the mechanism of absorption effects has not yet been evolved.

(f) Physical Interpretation. The phenomena observed following King shot were fundamentally the same as those described in connection with earlier tests (Operations Greenhouse, Buster, and Snapper) except that the geometry was somewhat different. In the earlier tests the ionosphere recorder was relatively near the blast, and the changes in electron density caused by the shock wave were viewed from a point which was almost directly underneath the highest point of the approximately spherical wave front. In the case of King shot, however, the sonic (or shock) fronts were oblique, and the pulses from the ionosphere recorder were reflected from the front of the shock wave. No basically new phenomena were observed, however, and the detailed analysis given above merely serves to corroborate the earlier conclusion that all effects observed were due to scattering, reflection, or refraction of the radio waves by the regions of increased ion density caused by the compressional wave from the detonation.

3.1.2 Mike Shot Data at Bikini

(a) General Description of Results. During Mike shot, a phenomenon occurred which had not been observed in connection with any previous atomic explosion. It was a sustained increase in the height of the F2 layer, commencing shortly after the expected arrival time of the sonic wave (due to the blast) at a point in the ionosphere directly above the recorder (see Fig. 3.10). Before the virtual height started to rise, the F2 ion density (as indicated by the critical frequency of the layer) began to decrease and remained below the normal range of values for $3\frac{1}{2}$ hr. The height increase began abruptly, as may be seen in the figure (the rate of increase being a maximum shortly after the onset of the effect), and lasted more than 3 hr. Then, for about an hour, stratification developed, one or two subsidiary "layers" appearing in the F2 region with their virtual heights moving rapidly downward. By this time (about $4\frac{1}{2}$ hr after the shot), the normal F2 layer had begun to reappear. During the ensuing hour, both its virtual height and critical frequency returned to normal and remained near the middle of the normal ranges. During the time when the F2 virtual height was increasing, there was an unusual amount of diffuseness, or "spread echoes," probably due to many returns from a region of great turbulence. Also noteworthy is the triangular area of diffuse echoes which appeared between 3 and 5 Mc (see Figs. 3.13 and 3.14), principally during the second hour following the blast.

All the effects described above have been found to occur during magnetic storms. A few selected quotations from articles describing ionospheric effects coinciding with magnetic storms will be given to illustrate the similarity.

Chapman and Bartels[8] state that "during magnetic storms the F2 layer (at night the F layer) seems to expand and move upward, the electron density being reduced sometimes to one-quarter the normal amount." Kirby et al.[7] write that the associated ionospheric effects (that is, "a marked increase of virtual heights, a decrease of ionization densities, increased diffusion of the F2 layer, increased separation of the F1 and F2 layers, and a sharpening of the F1 critical frequency") indicate "an expansion and diffusion such as might be produced by heating." Berkner and Seaton[8] in discussing a particular storm say: "Evidence indicates large spatial tilts of isoionic surfaces... These spatial tilts were followed by rapid rise of height and increase of scattering."

(b) Detailed Description of Results. Selected ionosphere records at Bikini (360 km from GZ) are shown in Figs. 3.11 to 3.15. The salient details of these pictures are:

12'30". Nighttime F layer, with a virtual height of 240 km and a critical frequency (for the ordinary trace) of 7 Mc, which is typical of the pre-effect records. The extraordinary critical frequency is 0.4 Mc higher.

16'45". Three distinct returns are seen at the lower end of the F trace. Analysis shows that one is the normal F trace and the other two are probably oblique returns from regions of strong local ion density to the west of the recorder, caused by the passage of the compressional

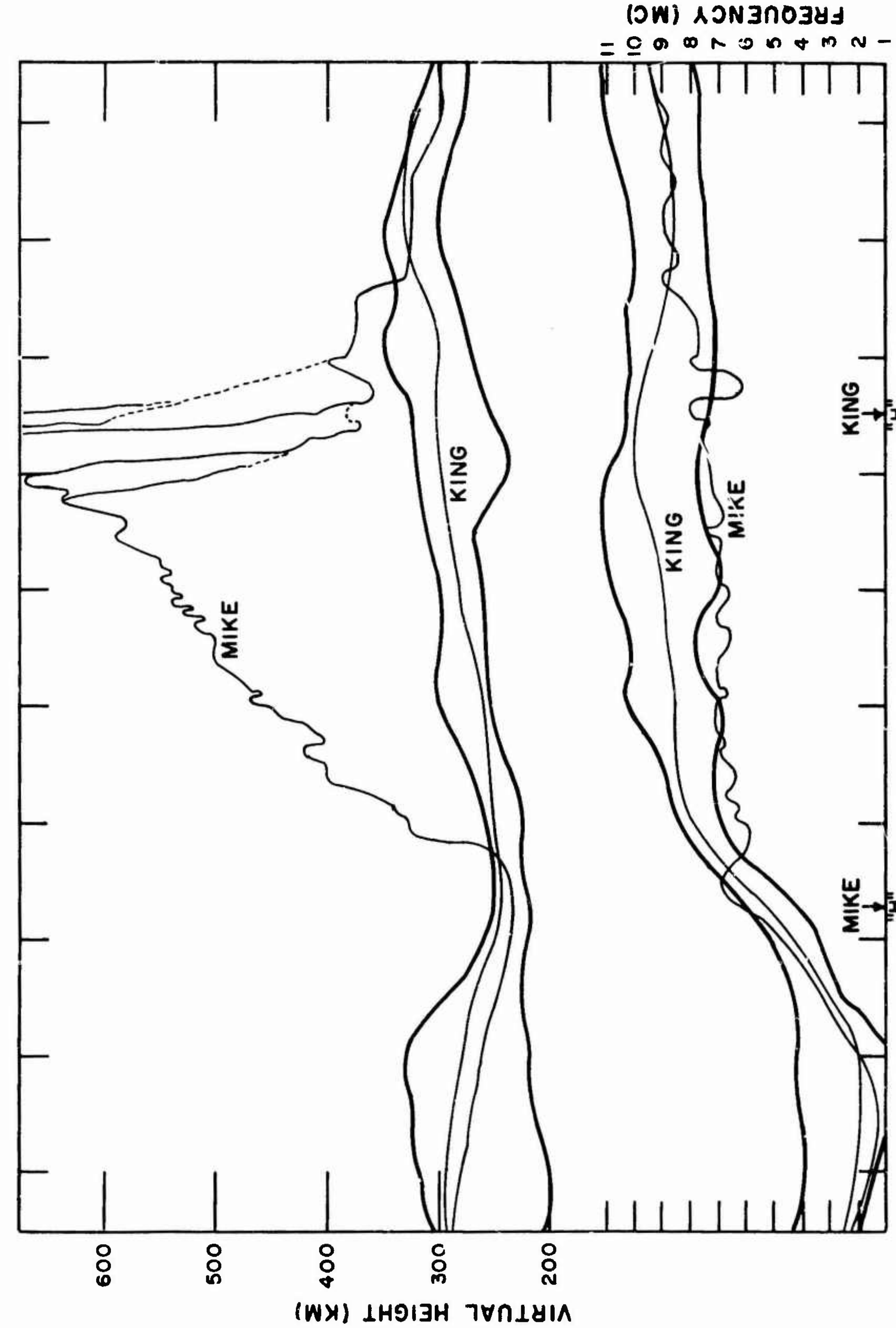

Fig. 3.10—Virtual height and critical frequency of the F2 layer at Bikini on Mike and King days. (Heavy lines indicate the range of values observed on nonshot days during this period.)

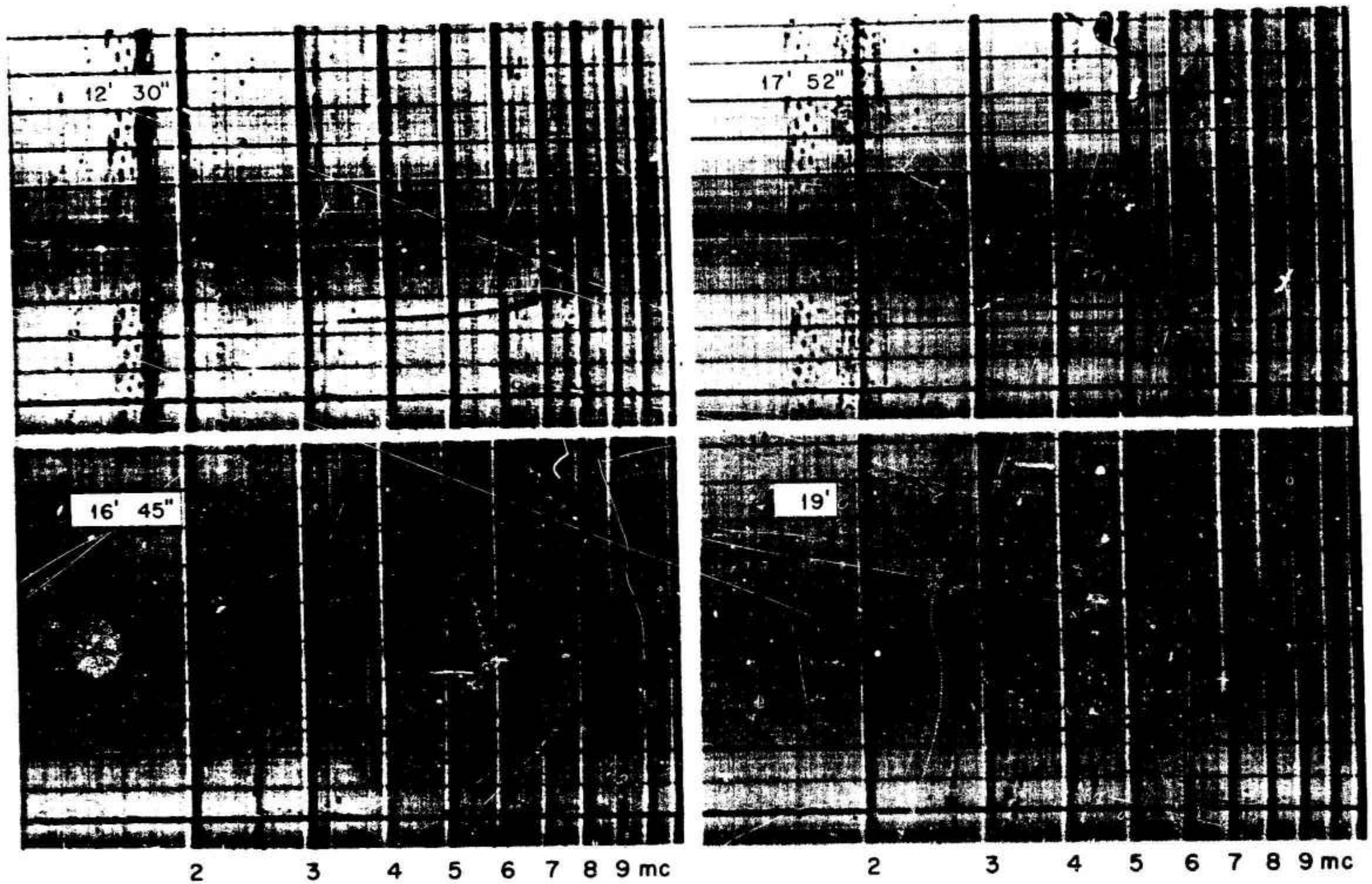

Fig. 3.11—Representative ionosphere records at Bikini (Mike shot), from H + 12 min 30 sec to H + 19 min. (Horizontal lines show 100-km height increments above ground level, the heavy line.)

wave through the ionosphere. That distortion of an ionized layer can cause oblique returns to be observed before the passage of the wave front overhead was shown in Sec. 3.1.1b. Furthermore, the presence of the two extra two-hop F traces implies the existence of an oblique two-hop mode of propagation similar to that described in Sec. 3.1.1d in connection with a like effect during King shot.

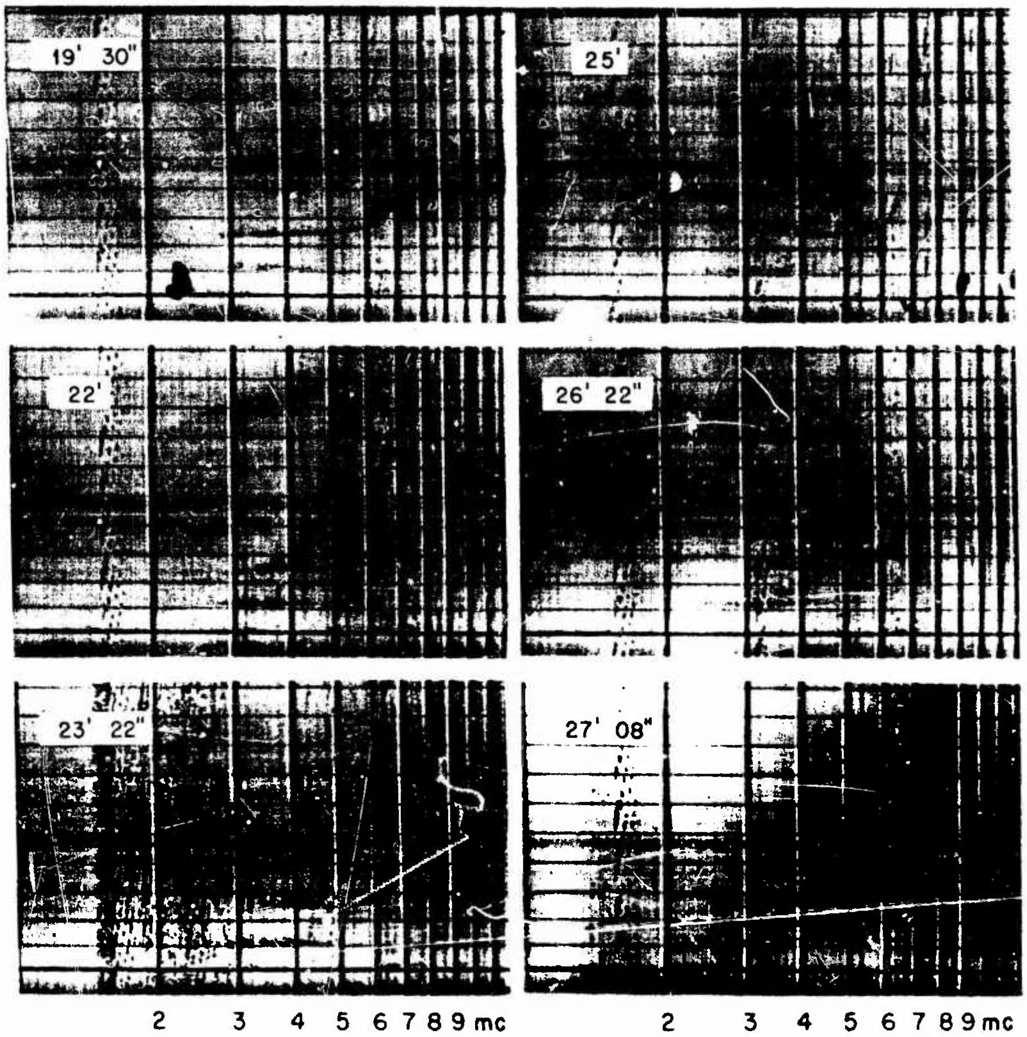

Fig. 3.12—Representative ionosphere records at Bikini (Mike shot), from H + 19 min 30 sec to H + 27 min 8 sec. (Horizontal lines show 100-km height increments above ground level, the heavy line.)

17'52". Two separate two-hop F traces are seen, neither of which is twice the one-hop in height. A three-hop return appears at frequencies for which there is no two-hop, and a two-hop return appears where there is no three-hop. All of these seem to indicate that the F layer has been tilted or distorted. A short segment of sporadic E, probably caused by the arrival of the compressional wave, is barely visible.

19'. The presence of numerous returns near the critical frequency is an indication of the beginning of ionospheric turbulence.

19'30". The turbulence has increased; several returns of a sporadic-E nature appear.

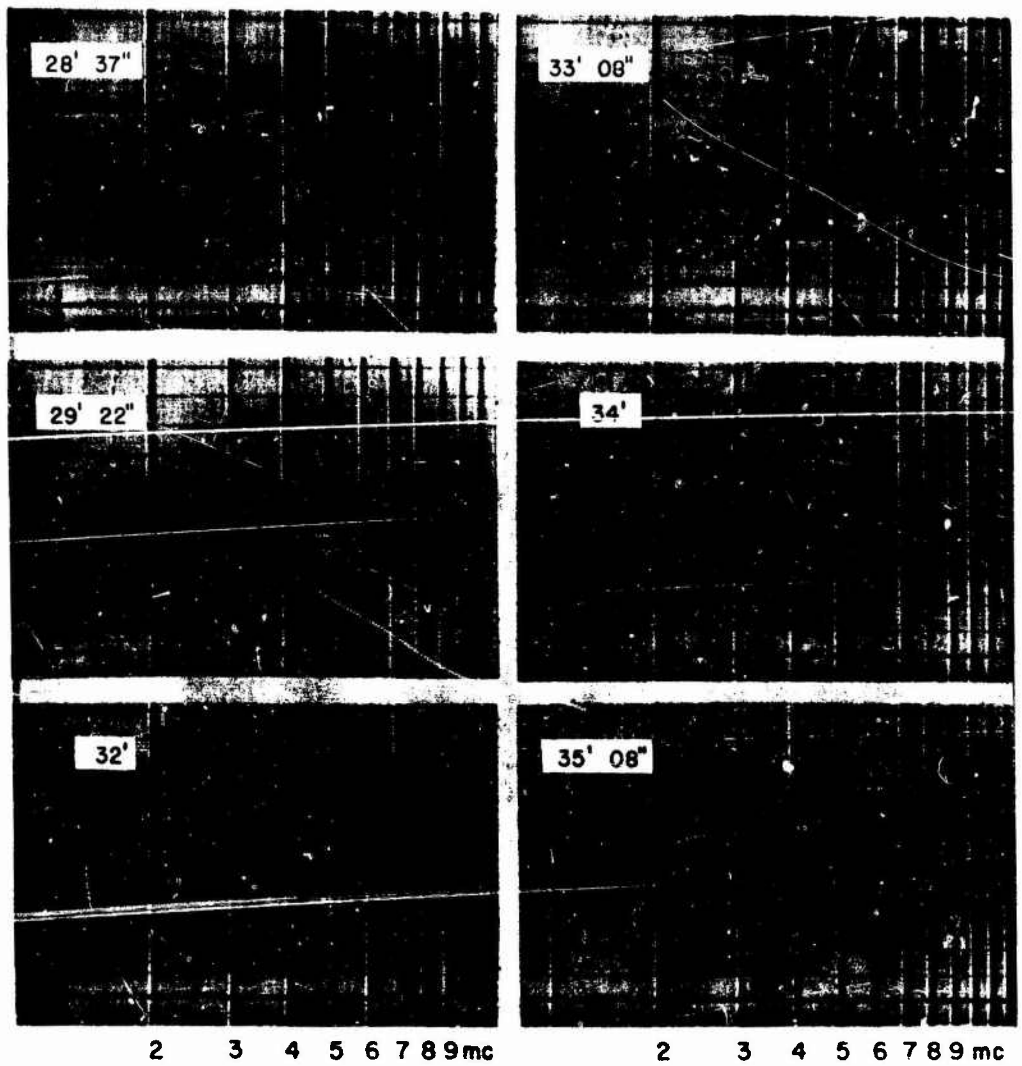

Fig. 3.13—Representative ionosphere records at Bikini (Mike shot), from H + 28 min 37 sec to H + 35 min 8 sec. (Horizontal lines show 100-km height increments above ground level, the heavy line.)

22'. The spread echoes have diminished near the critical frequency but have increased along the rest of the F trace. Sporadic E is stronger.

23'22". The difference in height between the ordinary and extraordinary rays at the low-frequency end has increased.

25'. Sporadic E appears at several distinct levels. An oblique F trace (which disappears 20 sec later) is seen on both sides of the 4-Mc marker at an apparent height of 350 km. Both the ordinary and extraordinary traces are seen.

26'22" to 29'22". At +25'45" an oblique F trace which rose with time was first observed. The increase of its apparent height at the rate of about 20 km/min, which may be traced in these four pictures, indicates that it was being returned from the back of a sonic front moving

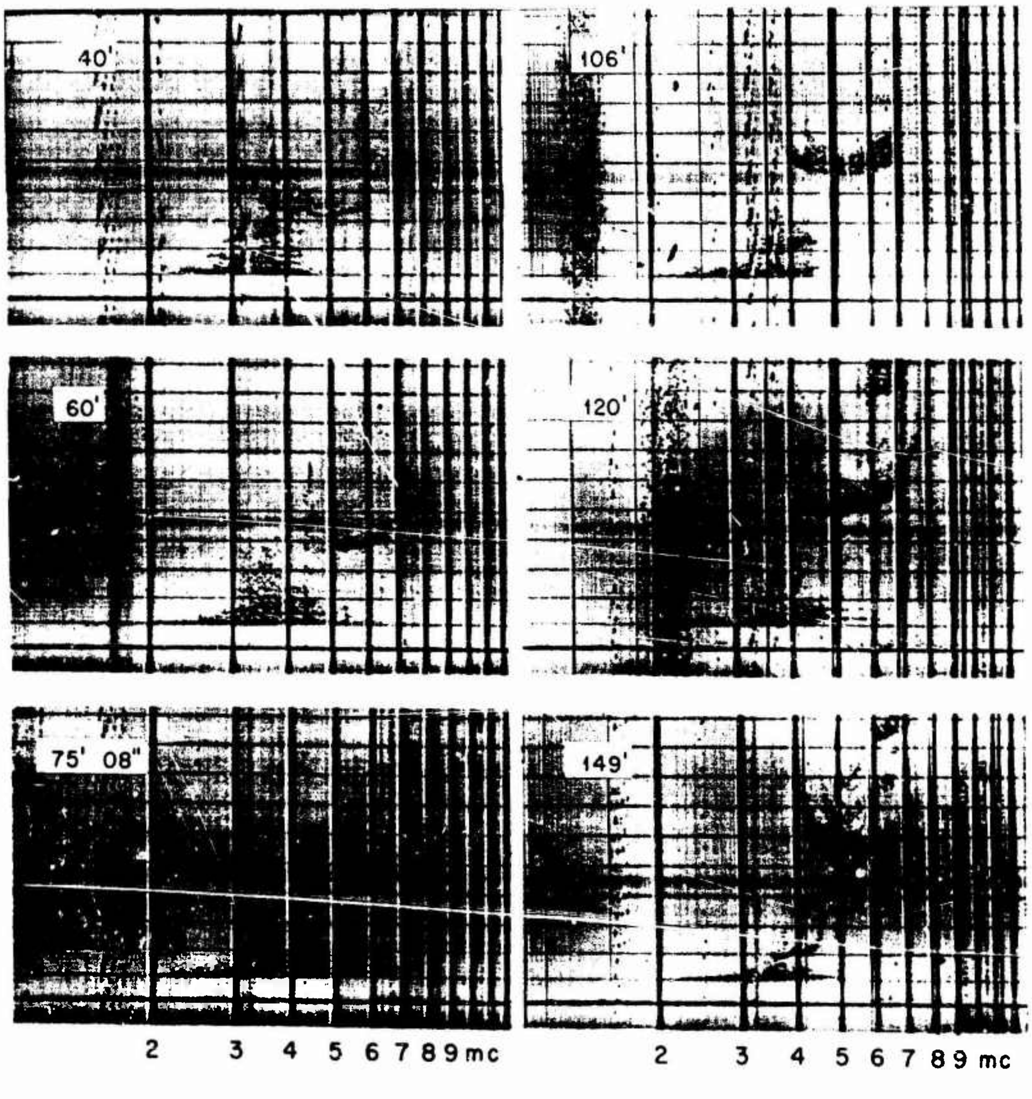

Fig. 3.14—Representative ionosphere records at Bikini (Mike shot), from H + 40 to H + 149 min. (Horizontal lines show 100-km height increments above ground level, the heavy line.)

away from the recorder. The apparent height of the trace places the front about 250 km away (or 610 km from the source), which agrees well with its computed location. The increase in frequency of the oblique trace, which may also be followed in the pictures, further corroborates the above hypothesis. It is similar to the *decrease* in frequency, described in Sec. 3.1.1b, in connection with King shot, when the sonic front causing the oblique trace was moving *toward* the recorder instead of away. Also noteworthy in this group of pictures is an increase in spread echoes, identified as scatter from the now much disturbed F layer.

32'. An oblique two-hop return is seen. There is also some indication of a one-hop oblique trace at 300 km.

33'08". At 460 km there is a one-hop oblique F trace which may well have been a continuation of the effect which began at 25'45".

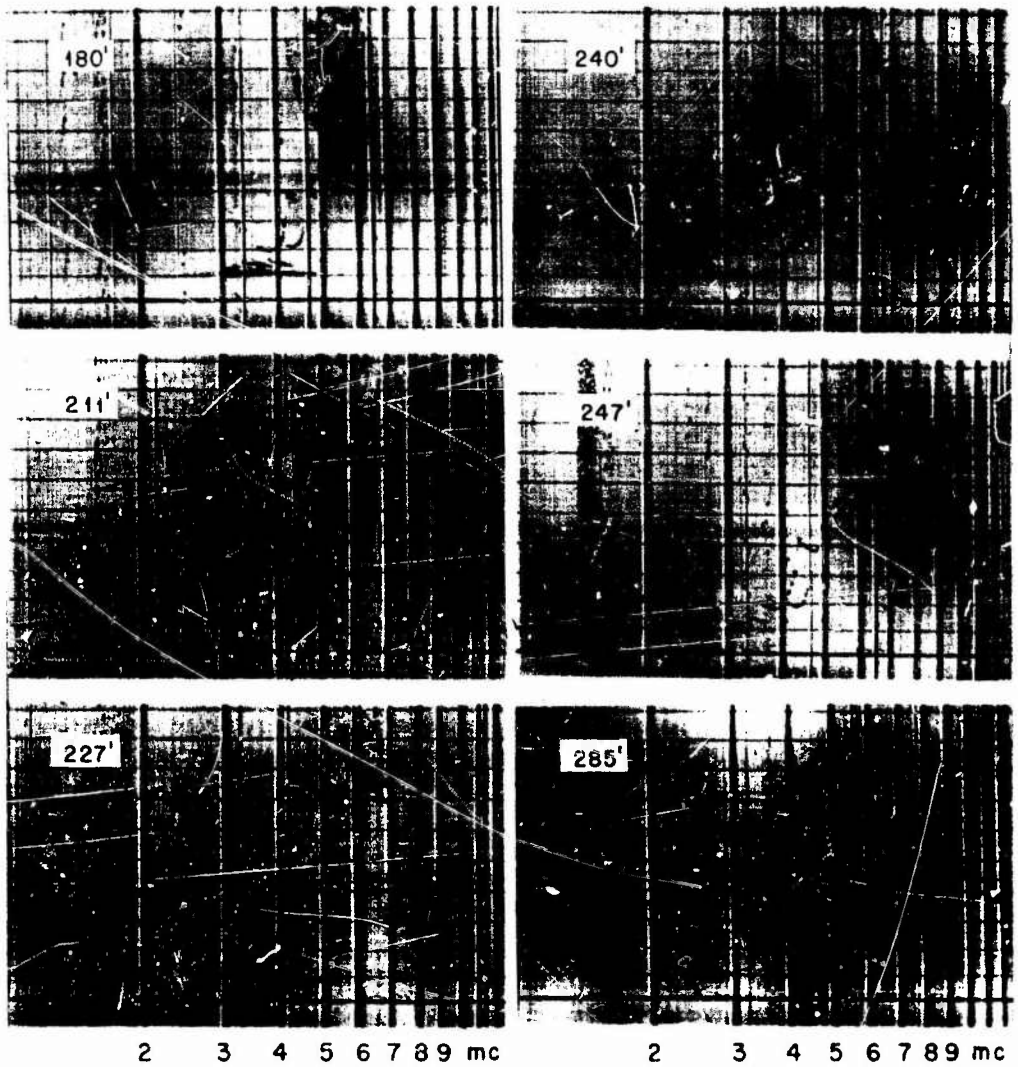

Fig. 3.15—Representative ionosphere records at Bikini (Mike shot), from H + 180 to H + 285 min. (Horizontal lines show 100-km height increments above ground level, the heavy line.)

34' to 35'08". An additional F trace appears slightly higher than the vertical return. It is assumed to have been an oblique reflection from a layer which was no longer horizontally homogeneous.

40'. The F2 height has increased 80 km since the first picture shown. There also is a hint of the normal development of an E layer and an FI layer as would be expected with the increasing elevation of the sun.

60' to 75'08". Prolific scattering in the E region and upward is noticed.

106'. The scattering has begun to diminish somewhat in the E region, whereas the reverse is true for F2. The height of the F2 layer is now 460 km. A sporadic-E trace between 6 and 7 Mc appears for just this minute.

120'. The F2 layer has risen to 480 km. Sporadic-E traces are seen at higher frequencies than the main conglomeration of returns in the E region.

149'. Two discrete levels of sporadic E are seen. Note also the clarification of F1 into a distinct layer as well as a definite E-layer return with a critical frequency of approximately 3.3 Mc. The F2 trace is broken between 5 and 6 Mc, indicating stratification of the layer. An oblique return appears at about 800 km. Two-hop F2 near the top of the picture is also apparently oblique.

180'. The F2 returns are very scattered, but the height of the layer is clearly 550 km. A sort of stratification is seen near the F1 critical frequency (4.25 Mc).

211'. F2 is now seen at 640 km. E and F1 layers now present their normal appearance.

227'. A reverse in curvature is seen in the F1 trace, indicating stratification. The main portion of the F2 trace appears above 700 km, but there are two subsidiary cusps between the F1 and F2 critical frequencies. Bulges in the electron-density distribution are indicated by these cusps which, in successive frames, progressed downward along the curve from the F2 to the F1 critical frequency. This phenomenon is represented in Fig. 3.10 where, between 1040 hours (H+205 min) and 1200 hours (285 min), there are several steeply slanted lines indicating the changing virtual heights of these descending stratifications.

240'. The upper bulge which occurred at 227' has moved down from 610 to 420 km, and another one can be seen starting at about 700 km. Stratification in the F1 layer continues.

247'. Three distinct layers are seen in the F2 region. The return at the greatest virtual height (the rising trace whose course has been followed throughout) has become much less pronounced, and, shortly after this picture, it disappeared from view altogether.

285'. This last picture is included to show that conditions have returned to normal except for oblique two-hop F2 returns which indicate that a tilt was still present in the F2 layer.

(c) Magnetic Effects. The similarity of the ionospheric effects observed during Mike shot to those occurring during a magnetic storm suggests the possibility that magnetic disturbances might also have been present. In order to check this possibility the original magnetometer traces recorded at Hawaii by the U. S. Coast and Geodetic Survey for a few days preceding and following the shot were examined. (Hawaii is the nearest magnetic station under U. S. jurisdiction.) Unfortunately, a magnetic storm had been in progress for about two days preceding the shot, and it was therefore impossible to say whether or not any magnetic effects were the direct result of the shot.

(d) Physical Interpretation. The main feature which distinguishes the results obtained during Mike shot from those previously observed is the increase in the height of the F layer which occurred over a period of several hours. This phenomenon was probably due to the heating effect of the shock wave and had not been observed during any of the earlier tests because no previous device remotely approached Mike shot in magnitude of energy release.

It is well known that a shock wave causes an irreversible heating of the medium through which it travels. If the magnitude of the energy involved were sufficient and the final temperature attained were high enough, the heated region would rise in the manner of a balloon (in accordance with Archimedes' principle). The rising column of air thus created would be surrounded by cooler descending air, which would flow in from all sides under the rising air mass. Thus a region of considerable turbulence would exist under the rising column and the zone between the rising and descending air also would be one of great turbulence. If any horizontal motion of the ionosphere existed (due to winds), the rising air mass would also be displaced

horizontally, and, when the turbulent region surrounding the ascending air column passed over the ionosphere recorder, an irregular return of the F2 layer to its normal level would be observed. That this sequence of events was actually observed gives credence to the general picture given above as an explanation of the ionospheric effects following Mike shot.

Furthermore, the initial heating of the ionosphere by the shock wave would be followed by an increase in volume and by a corresponding decrease in density. This decrease in density would have had to occur before the F2 layer started to rise because the rise would be a direct result of the density change.* Such a decrease in electron density was observed preceding the rise of the F2 layer. Examination of Fig. 3.10 indicates that the density (measured by the critical frequency) started dropping at about H + 15 min and continued to fall below its normal trend line until about H + 35 min, at which time it leveled off and the F2 layer began to rise rapidly.

Table 3.1—ANALYSIS OF POSSIBLE MODES OF C-W TRANSMISSION (KING SHOT)

Mode	Theoretical relative field intensity, db	Comments
One-hop E	3.5	Low field intensity due to long path in absorption region (D layer)
Two-hop E	2.0	Still longer path in D region
One-hop F1		Does not penetrate E layer
Two-hop F1	11.5	Operating frequency just below MUF* for this mode
One-hop F2		Does not penetrate E layer
Two-hop F2	9.5	Weaker than two-hop F1 owing to longer path length

*Maximum usable frequency.

The spread echoes observed were doubtless caused by the turbulence set up, particularly under the rising air mass. These spread echoes were particularly noticeable in the E- and F1-layer traces. It is interesting to note that these two layers started to form at their usual height and time of day, in spite of the disturbance caused by the turbulence. This may indicate that only the region above the F1 layer was forced to rise by the heating due to the shock wave, or else it may indicate that the processes of ion formation in the E and F1 regions are such that ions are formed more rapidly than they can be removed by convection.

3.2 C-W TRANSMISSIONS

3.2.1 King Shot

Analysis of the airplane-to-ground transmission involved a preliminary determination of the mode or modes by which the signal was propagated. The distance, frequency, and time of day were considered in this analysis. The results, determined from ionosphere records at Bikini and theoretical field-intensity charts, are tabulated in Table 3.1.

*Under appropriate conditions, as will be fully discussed in Chap. 4, the decrease in atmospheric density is accompanied by a corresponding decrease in electron density.

Since it is apparent that two-hop F1 and two-hop F2 would be the predominant modes, and since the preshot signal intensity received was quite level, the signal is assumed to have arrived by one or the other of these modes but not by both. For each mode, there are two distinct paths possible for a signal transmitted from a high elevation, one path striking the ionosphere directly and the other reflected at the earth's surface first and then from the ionosphere. The rays following these two paths may arrive at the receiver in phase, completely out of phase, or in some intermediate relation. Thus the signal may be reinforced or entirely canceled out. Charts prepared before the tests indicate that, at the given distance and transmitting-antenna height, the only received mode would be two-hop F1, since two-hop F2 would be subject to destructive interference. Corroborating this hypothesis is the fact that, during the north and south turns when the airplane may not have maintained a constant altitude, the signal level exhibited frequent dips from the maximum. These dips are considered to have been interference fading which occurred when the two-hop F1 mode was weakened and the two-hop F2 mode was strengthened owing to a change of transmitter height.

Figure 3.16 is a photograph of the actual recording of the signal shown on the S meter at Bikini from $+2\frac{1}{2}$ to +11 min. For $\frac{1}{2}$ hr before the shot and until +3 min, a signal strength of S5.5 was recorded, and it remained steady at this level about 90 per cent of the time. Just before +3 min the double identifying break can be seen, signifying the end of a northern turn. At +3 min the signal level dropped, reaching S3 at +4 min and remaining at about that level until +5 min 45 sec.

It is to be noted that the transmitted beam should have struck the ground, in its two-hop passage, at a point very close to GZ. The shock wave, rising at the approximate rate of 20 km/min, should have reached the D region in 3 min. That the signal was greatly attenuated at this time may mean that the shock wave, acting in some manner on the ions of the D region, suddenly augmented the absorption there.

From $+5\frac{3}{4}$ to $+9\frac{1}{4}$ min the signal varied between S3 and S5.5 with pronounced fading at the higher levels. The increase in signal strength was probably due to the introduction of M-type modes whose paths did not cross through the disturbed portion of the D region with its temporarily increased absorption; the principal M-type mode involved consists of a ray path having two reflection points in the F2 layer with an intermediate upward reflection from the shock front in the E (and later the F1) region. The geometry of this effect was discussed and illustrated in the Operation Snapper report[9] in connection with pulse-transmission experiments between Mather AFB and Navajo OD, a distance of the same order.

The signal remained at or near the noise level with random fading (below S3) until +21 min. It is presumed that the almost complete absence of signal from $+9\frac{1}{4}$ to +21 min was due to a combination of D-region absorption and scatter in the E and F1 regions as a result of the shock wave. From +21 to $+42\frac{1}{2}$ min a signal which may have been propagated via the E layer appeared at the S3 level, at first intermittently and then more steadily. The two-hop F1 mode was apparently absent. It would probably have been present but for a reduction in the F1-layer critical frequency allowing the c-w signal at 5.6 Mc to penetrate. Examination of the recording showed that at $+42\frac{1}{2}$ min, the original two-hop F1 mode had clearly reappeared, coincident with the return of the F1 critical frequency to its preshot value.

A graph showing the gross changes in relative signal level for both tests is presented as Fig. 3.17. The decline in signal strength that occurred after King +50 min is not considered to have been a result of the explosion. Rather, it was due to the normal increase in absorption as the time neared local noon.

It appears, then, that the detonation affected this particular circuit for 18 min, starting 3 min after the shot; that is, from the time of arrival of the shock front in the D region until it passed overhead at the ends of the path. That the signal did not return to its original level until about $\frac{3}{4}$ hr after the shot can be attributed to the fact that the predominant mode had been just below the MUF and a slight decrease in critical frequency prevented its propagation.

3.2.2 Mike Shot

The most interesting portion of the recorded signal (from +8 to +12 min) is reproduced as Fig. 3.18. The time constant of the recorder circuit was too long to permit the 1-sec

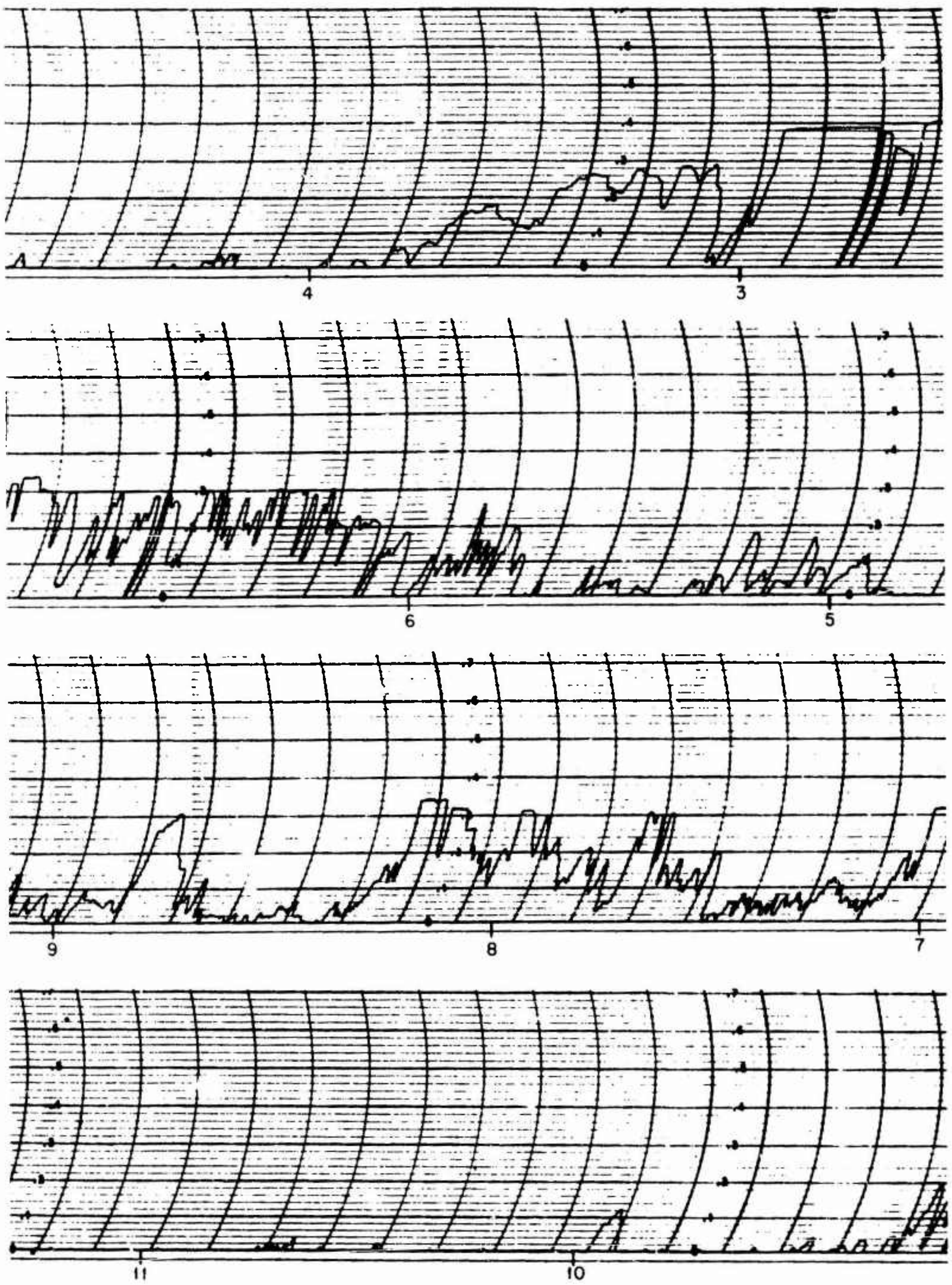

Fig. 3.16 — C-w signal, King day. (Segments are consecutive from top downward. Time, reading from right to left, is indicated in minutes from H hour by the numbers 3 through 11.)

identifying breaks to be seen. However, there is no doubt that this was the signal from the airplane. Rapid variations were, of course, somewhat integrated because of the long time constant.

There seems to have been some effect present for about 14 min, starting at + 9 min. At that time a strong signal, which had been at a level of S6.5, plummeted to S2.5, the noise level.

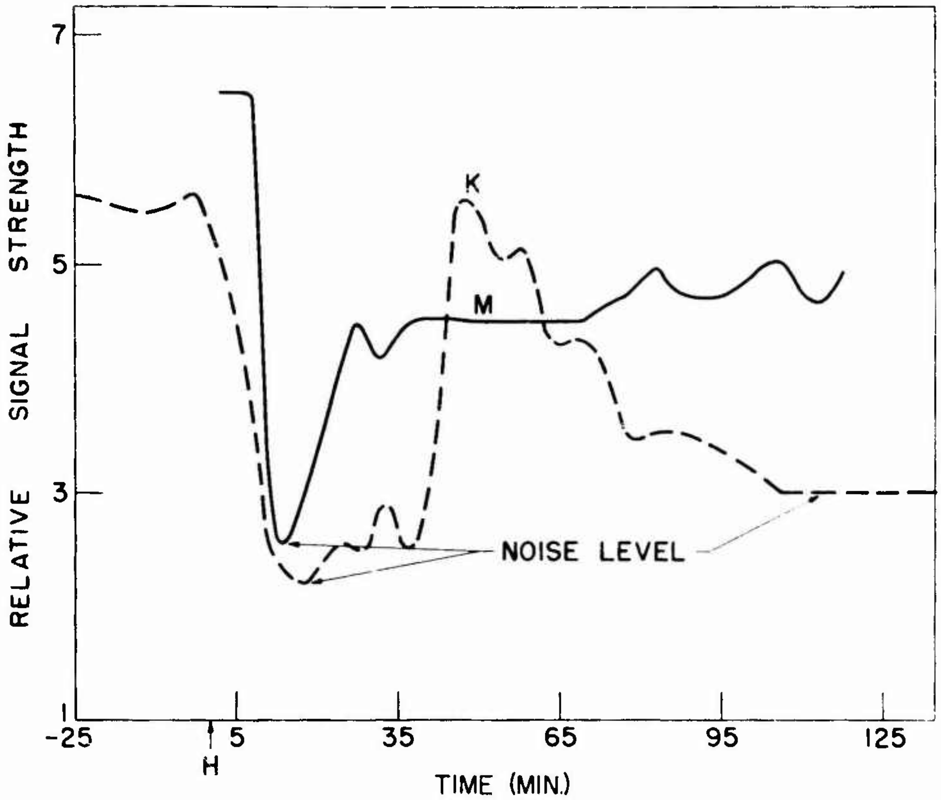

Fig. 3.17—Relative signal strength, c-w transmission.

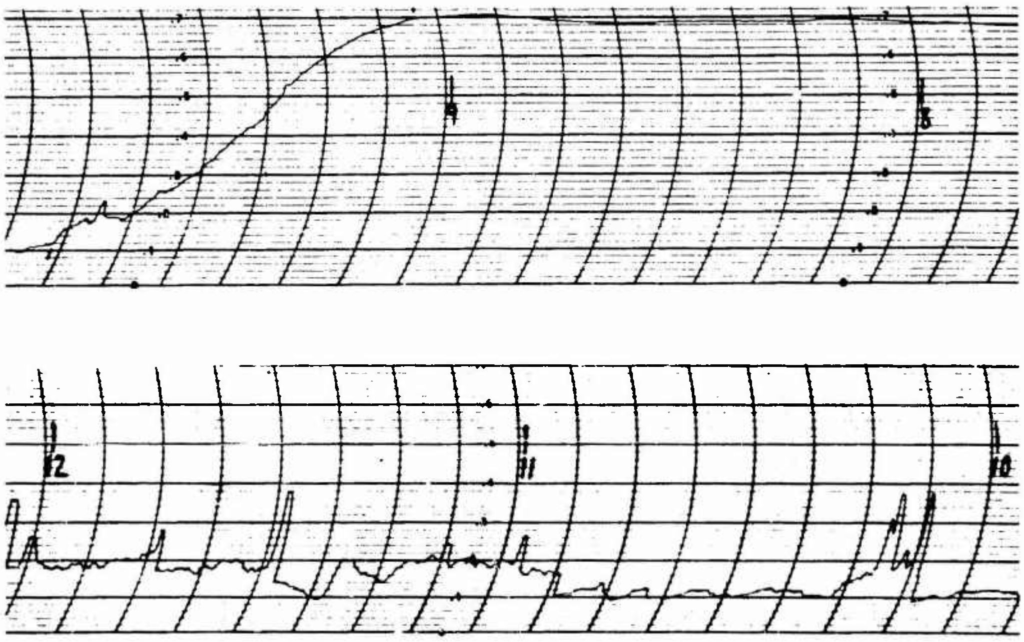

Fig. 3.18—C-w signal, Mike day. (Segments are consecutive from top downward. Time, reading from right to left, is indicated in minutes from H hour by the numbers 8 through 12.)

The signal strength then began a slow, generally upward trend, with intermittent bursts to S4.5 during the climb. The final level of S4.5 was reached at +23 min, where it remained, although there was a slight increase to S4.8 at +67 min. (See Fig. 3.17.)

Since only a single layer (nighttime F) was present at the time of detonation of Mike, one-hop F was by far the most likely mode of propagation. The attenuation, starting at +9 min, is similar to the effect which began at +3 min, observed in connection with King. Since one-hop, and not two-hop, propagation was involved during Mike, it took longer for the compressional wave from the blast to reach a location in the D region through which the transmission path passed. The intermittent traces of stronger signal were probably due to M-type paths, such as discussed in Sec. 3.2.1, with the increased ion density, due to the compressional phase of the sonic wave, serving as the upward reflecting region. By +23 min a blanketing sporadic-E layer had developed (see Sec. 3.1.2), permitting transmission via sporadic E but eliminating

Table 3.2—FREQUENCY OF HITS (GUAM-KWAJALEIN CIRCUIT, MIKE DAY)

Kwajalein to Guam (9205 kc)		Guam to Kwajalein (8935 kc)	
Minutes from H hour	No. of hits per 5 min	Minutes from H hour	No. of hits per 5 min
Until −24	Garbled message	Until H hour	Completely unintelligible; impossible to determine the no. of hits
−21	5		
−16	7		
−11	0		
−6	0		
−1	12		
+4	10	+3	40
+9	32	+8	38
+14	2	+13	7
+19	0	+18	1
+24	0	+23	1
+29	0	+28	28
+34*	0	+33*	4

*No hits after this time.

other modes. Thereafter, unlike King, as Fig. 3.17 shows, the signal level remained steady and then rose gradually, in spite of the normal morning increase in absorption. The trend of the level is assumed to have been normal and due to the development of the E layer.

3.3 TELETYPE MONITORING

3.3.1 Guam-Kwajalein Circuit

(a) Mike Day. Analysis of the hard copy at the transmitting and receiving ends of both directions of this two-way circuit (see Fig. 2.1) showed that the frequency of hits had definite peaks shortly after shot time. There was a decided difference between the times of occurrence of these maxima for the two directions of propagation (see Table 3.2).

Signal-strength figures marked on the hard copy indicated that prior to shot time the transmitting frequencies were above the MUF. The propagation was, therefore, via scatter, and thus the intelligibility of the signal in both directions was low. However, as is apparent from Table 3.2, the message on the higher frequency became clear first. Although, with rising MUF, one would expect good reception on the lower frequency first, it is entirely possible that the 8935-kc signal arrived by both the ordinary and extraordinary modes and destructive interference between the two was responsible for the greater number of hits before shot time. Possibly only the extraordinary mode of the 9205-kc signal was being propagated at this time;

hence no interference resulted, and it was intelligible. If this explanation is correct, it is possible that, as the value for the MUF rose with rising sun, destructive interference ceased at the lower frequency but commenced and then stopped at the higher frequency. This would explain the large number of hits at +9 min at Guam, since this was far too early for a compressional wave traveling at normal sonic velocity to have reached the Guam-Kwajalein great-circle path, and to assume a greater sonic velocity would be contrary to all other results in these tests. The large number of hits at +28 min on the Guam-to-Kwajalein transmission appears to indicate a shot-caused effect due either to increased absorption in the D and E regions, as discussed in Sec. 3.2, or possibly to some consequence of the rising of the F layer, described in Sec. 3.1.2. However, the increase in hits is more likely to have been a continuation of the normal interference effects.

All this is mentioned not as an authoritative explanation of the effects observed but rather as a speculative attempt at understanding what happened. As a further conjecture, there is a possibility that the dissimilarity between the two directions was not a function of the frequency but was due to contrary paths across the earth's magnetic field.

Yet, even if the effect noticed was due to the shot, which is not at all certain, it lasted for only a few minutes and hence did not appreciably disturb communications.

(b) King Day. The two-way circuit was in operation on this day, but there was no significant loss of intelligibility, either shot-caused or otherwise. Since King shot took place near midday, ionospheric conditions were relatively stable compared with those existing at the time of Mike.

3.3.2 Guam-Hickam Circuit

(a) Mike Day. Two separate circuits involving four different frequencies between 10 and 16 Mc were in operation. No effects that could possibly be associated with the shot were found upon close scrutiny of the teletype copy. The reception was good at all times except when propagation conditions for the particular frequency were expected to be normally poor.

(b) King Day. Only one circuit was used, with transmission frequencies at both ends near 15 Mc. Again, no effect of the detonation could be discerned. The Hickam-to-Guam intelligibility was very good with a nearly continuous high signal level. The reception of Guam at Hickam was also good except for a low signal level and a high hit frequency from H−5 min to H+28 min, which was probably the result of frequency drift since the receiver had to be retuned at H+24 min.

3.3.3 Okinawa Transmission Intercepted at Bikini

Since the teletype signal which was to have been intercepted on Mike day could not be received, the Okinawa-to-Kwajalein transmission was monitored and its signal level recorded. Since this was unplanned, the received copy could not be collated with what was actually transmitted. However, the number of hits could be approximated owing to the nature of the text. A tabulation of the estimated hit frequencies, as well as the mean signal levels, is given in Table 3.3.

From Table 3.3 it is seen that the signal strength fell suddenly just after H hour. However, the original recording shows that the decrease began at 1 min after Mike shot and thus occurred too soon to be accounted for by the mechanism which apparently operated on the c-w signal from the airplane (arrival of the sonic wave at the radio path in the lower ionized regions of the atmosphere and consequent absorption or scattering). The drop was probably caused by the normal "predawn dip," as it was still night over the entire western end of the path. Attenuation due to the sonic wave, if present, would have been masked by this normal effect. The high number of hits observed near +13 min may or may not have been due to the effects of the shot. The time of occurrence agrees with the probable sonic travel time, but the likelihood that the predawn dip had caused the signal level to be low leads to doubt as to the cause.

Table 3.3—FREQUENCY OF HITS AND STRENGTH OF SIGNAL (OKINAWA AT BIKINI, MIKE DAY)

Minutes from H hour	No. of hits per 5 min	Mean relative signal strength
−12	5	17
−7	0	
−2	3	
+3	2	6
+8	17	6
+13	25	7
+18	14	7
+23	(Poor; cannot count hits owing to no transmitted text)	8
+28		9
+33	Garbled	9
+38		7
+43		8
+48		8
+53		5
+58 to +113	About 3 to 4	7 at beginning, 10 at end
+113 to +165	Garbled	5

3.3.4 Manila Transmission Intercepted at Bikini

A signal-level recording of the Manila-to-Kwajalein teletype circuit intercepted at Bikini on King day furnishes what is perhaps the most interesting information in this section. The solid line of Fig. 3.19 is a plot of 10-min averages of the received signal strength. The presumed downward trend of the signal level due to normal daytime absorption is shown as a dashed line. Since the mid-point of the path was just about in the dawn region at shot time, it is apparent that increasing attenuation was to be expected.

The received signal is seen to have departed greatly from the general trend line, starting about 5 min after shot time or at approximately the time which it would take the sonic wave to reach the D region along the great-circle path between Manila and Bikini (see Fig. 2.1). As was the case for the airplane-to-ground c-w transmission, its effect appears to have been to increase the absorption or scattering in that region. The signal level then dropped faster than the trend line, reaching its greatest departure from the assumed norm at +35 min. This may be accounted for by consideration of the path geometry and its relation to the expanding spherical sonic front. The optimum Manila-Bikini path was two-hop, and, from +5 to +35 min, more and more of the downcoming radio wave would have been passing through the affected portions of the D and E regions. By +55 min the effects of the disturbance upon these regions had mitigated, and the deviation from the expected normal signal strength became small.

Unfortunately, because employment of this circuit had not been planned, the transmitted text was not available for comparison with the received copy; thus no count of the actual number of hits was possible. However, the intelligibility could be judged because test tape was used the majority of the time, and there appeared to be little change in the number of errors, despite the extra attenuation due to the shot.

3.4 EFFECTS AT GREAT DISTANCE

3.4.1 Effect at Guam

Experience has indicated that infrasonic waves should have reached Guam (about 1900 km from the source) between 1 hr 35 min and 1 hr 45 min after the shot. Further, since the oc-

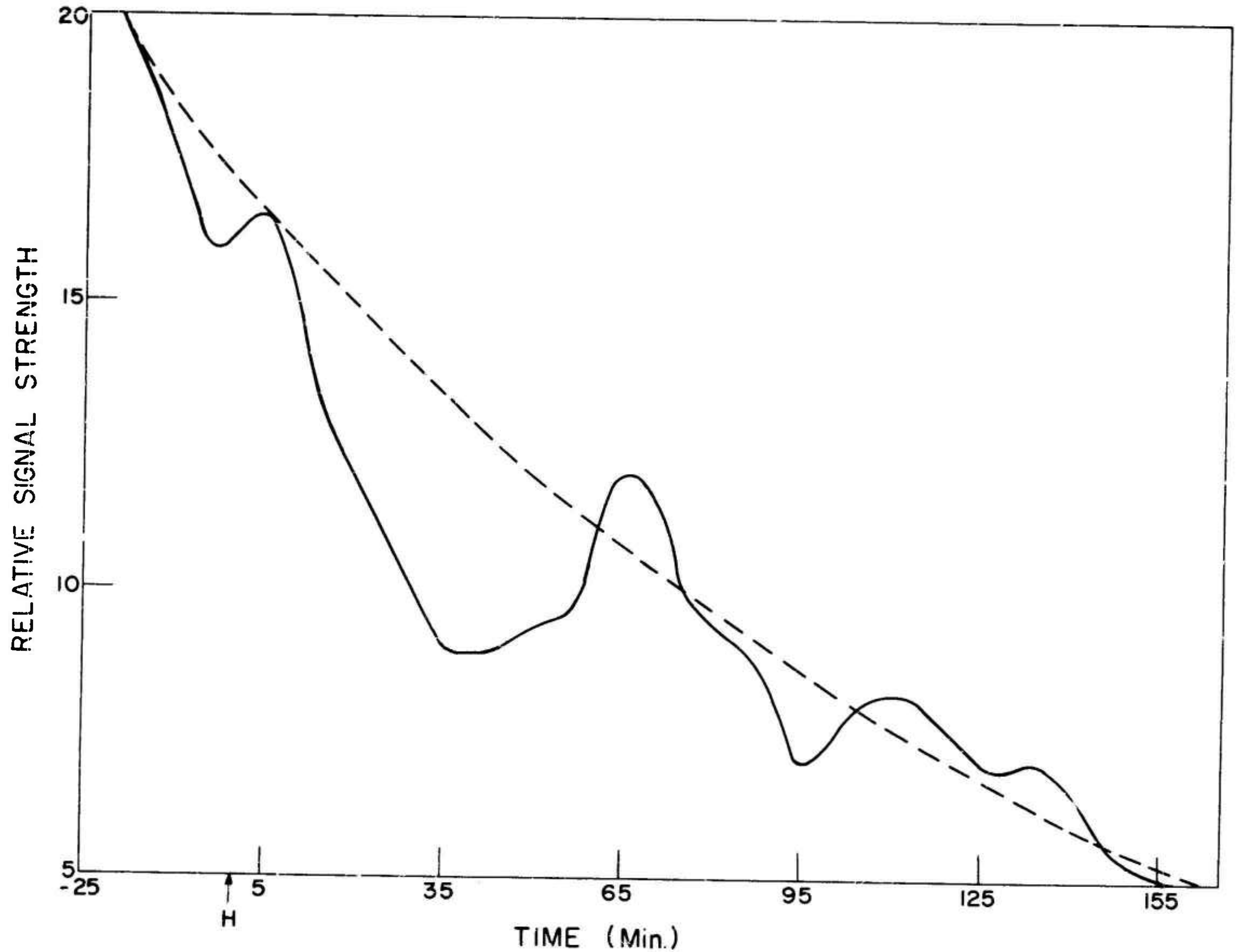

Fig. 3.19—Relative signal strength, Manila teletype transmission intercepted at Bikini, King day. (Dashed line is presumed normal diurnal trend.)

currence of effects on the ionosphere had been found in the past to approximately coincide with the arrival time of the compressional wave, and since sonic velocity in the upper ionosphere is known to be much greater than it is at the ground, any effect to be found in the F-layer traces of the oscillograms at Guam was expected by 1 hr 45 min, at the latest. No effect was noted for at least 2 hr after either Mike or King shot during the study of ionosphere records obtained there.

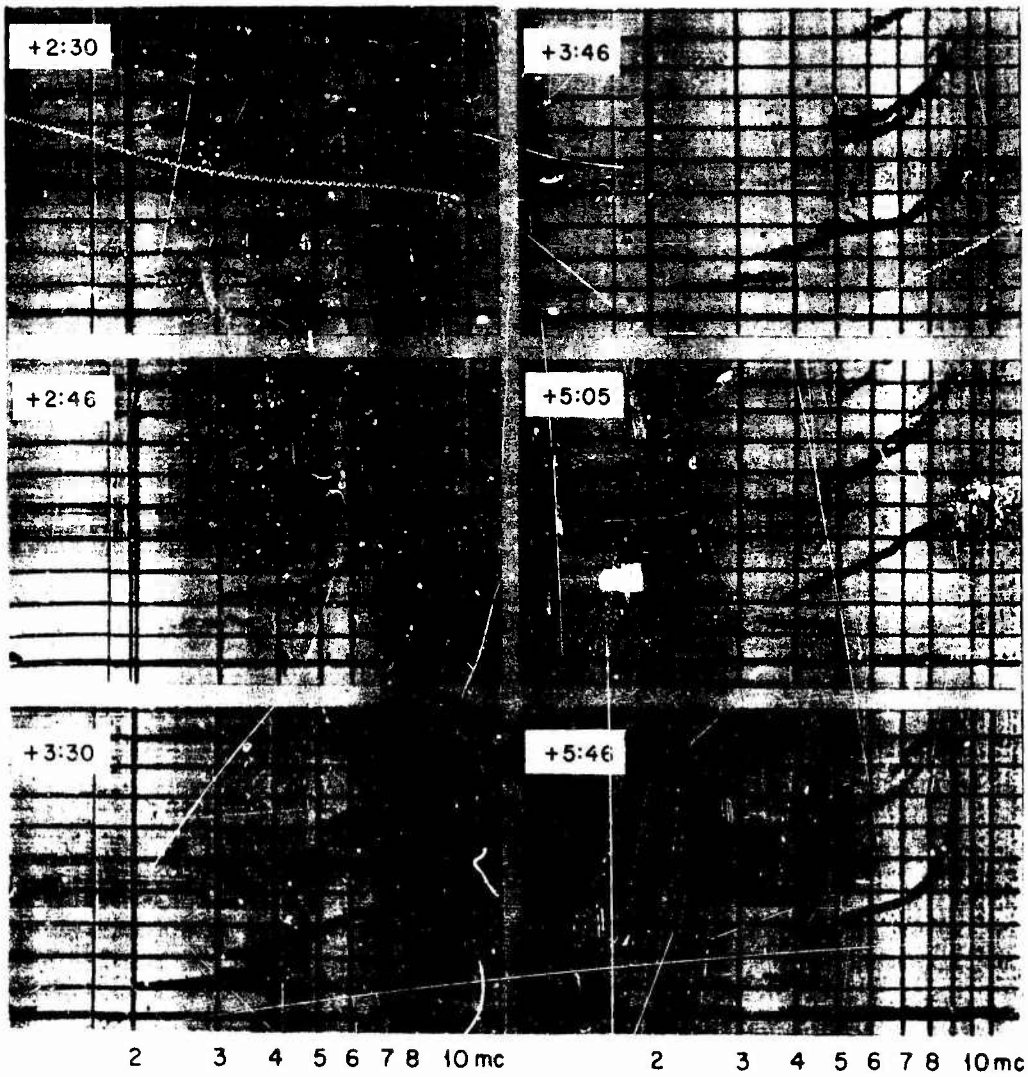

Fig. 3.20—Representative ionosphere records at Guam (Mike shot), from H + 2 hr 30 min to H + 5 hr 46 min. (Horizontal lines show 100-km height increments above ground level, the heavy line.)

However, a marked perturbation was found in the second reflection from the F layer, starting $2\frac{1}{2}$ hr after Mike shot and lasting nearly 4 hr (see Fig. 3.20). This two-hop trace took on various unusual aspects and, on the whole, indicated a disturbed, effectively tilted layer. The tilt is deduced from an extra two-hop reflection which appeared at a virtual height other than twice the one-hop height. It is assumed, therefore, that the extra trace was due to an oblique ray reflected vertically from the earth at some distance from the recorder, somewhat in the manner shown in Fig. 3.9.

3.4.2 Effect at Maui

An F2-layer disturbance was seen in the ionosphere records obtained at Maui, 4500 km from Eniwetok, from $4^3/_4$ to $6^1/_4$ hr after Mike shot. That this disturbance may have resulted from the blast is indicated by the fact that the elapsed times between Mike shot and the first appearance of the disturbance in the records at Maui and at Guam were proportional to the respective distances. By comparison of Fig. 3.21 with Fig. 3.20, it is seen that, although the possible effect at Maui is considerably less distinct than that at Guam, it is similar in this respect: a two-hop reflection appears at a height other than twice the one-hop height, thus indicating a local tilt in the F2 layer.

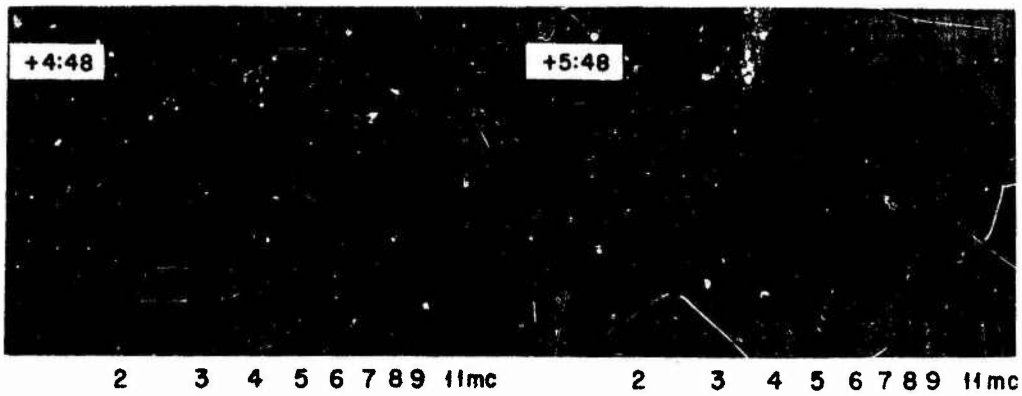

Fig. 3.21—Representative ionosphere records at Maui (Mike shot), at H + 4 hr 48 min and H + 5 hr 48 min. (Horizontal lines show 100-km height increments above ground level, the heavy line.)

3.4.3 Velocity of Disturbance

A rough calculation of the average velocity of propagation of the disturbance shows it to be 13 km/min to both locations. The time interval used in each case is from H hour, 1915Z, to the time of the first indication of the effect in the two-hop F trace (2139Z at Guam and 0103Z at Maui). The distance used is the great-circle distance between the blast and each ionosphere recorder.

The time interval is subject to possible error due to the infrequency of the data, there having been a record 9 min earlier at Guam with no apparent effect, one 3 min earlier at Maui with a possible effect (but in the three-hop trace), and one 33 min earlier at Maui with no apparent effect. In addition, the first indication of the effect at Guam is questionable, but the effect was surely present 6 min later. The distance is also subject to error, since the disturbance in the ionosphere was not directly overhead at the time the effect was first observed but may have been as much as 50 km away.

Furthermore, no account is taken of the time needed for the blast energy, responsible for the initiation of the traveling disturbance, to reach the F2 layer. However, neglecting this time might not produce a significant error in estimating the velocity of the disturbance. A compensating error in distance might occur if the outward motion of the disturbance began at some horizontal distance (say 150 km) from the point directly over the explosion.

3.4.4 Effect at Okinawa

As a further check of the effect at great distances, the regular ionosphere records, taken by the 9465th Technical Service Unit on Okinawa (3950 km from the blast), were obtained and

examined. The expected time of the effect, based on a velocity of 15 km/min, was 0018Z. The oscillogram at 0015Z showed nothing unusual. The next record, taken at 0030Z, definitely contained evidence, in the three-hop F trace, of a local tilt in the F layer. The two-hop trace may also have been affected. The two records taken during the next minute each exhibited the same anomalies, but more clearly. The ensuing oscillograms (at 0044Z, 0045Z, 0046Z, 0100Z, and thenceforth) appeared to be normal.

3.4.5 Periodic Variation of Electron Density

Further work with the data from Guam revealed that there had been a more or less regular increase and decrease in F2 critical frequency, starting at about the time when the first effect

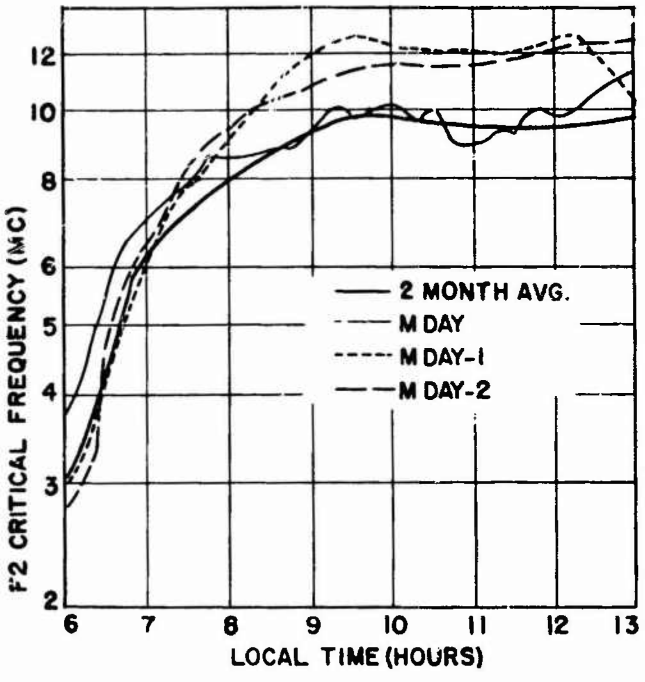

Fig. 3.22—Critical frequency of the F2 layer at Guam; Mike day, two preceding days, and October–November 1952 average. (H hour was at 0515 hours local time.)

appeared in the oscillograms (0739 local time) and lasting about $4\frac{1}{2}$ hr. (If there had been fluctuations in virtual height, they could not have been delineated because of the frequent lack of a cusp between the F1 and F2 traces.) A plot of the F2 critical frequency on Mike day is given in Fig. 3.22; included for comparison are corresponding curves for the two preceding days as well as one showing the average of the monthly median critical frequencies for the two proximate months.

Three observations may be made from this graph. First, an abnormal effect seems to have set in at about the time the multiple two-hop trace appeared (0739 hours local time). This effect evidently involved fairly large variations in the local F2 electron density (see Eq. 3.1). Second, the variation of critical frequency (electron density) was roughly periodic, the average period being about 40 min. Third, during the $4\frac{1}{2}$ hr of fluctuation there was a depression of the critical-frequency curve from its previous values about 1 Mc above the two-month average to values near the average. This implies that the electron density was about 20 per cent lower than it might have been without the disturbance.

A further discussion of such periodic variations in F2-layer parameters is given in Chap. 4, Sec. 4.2.

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CHAPTER 4

DISCUSSION

4.1 THE RISING F2 LAYER

The only ionospheric effect observed during Operation Ivy which was basically different from those previously described (in reports of Operations Greenhouse,[1] Buster,[2] and Snapper[3]) was the rising F2 layer which followed Mike shot. The abnormally reflected, refracted, and scattered radio signals, observed during those former operations and also during King shot of Operation Ivy, resulted directly from local increases in ion density caused by the blast wave, whereas the rising F2 layer observed after Mike shot was the result of an entirely different mechanism, namely, the heating effect of the blast wave. This phenomenon was not observed following the earlier shots because the energy remaining in the blast wave at ionospheric levels was far too low. In the case of Mike shot, however, the energy release was so large that it heated a region of the earth's atmosphere which was approximately hemispherical in shape and which had a radius of several hundred kilometers. This hemisphere should not be considered as having had a sharp boundary; a transition region some tens of kilometers in thickness probably existed.

The thermal energy was imparted directly to the hemisphere by the shock wave. Since the passage of a shock wave through a medium causes a nonadiabatic rise in temperature, the air in this region would not have returned to its original temperature but to a somewhat higher value. Such an increase in temperature would be accompanied by an expansion of the heated region, with a corresponding decrease in density. This means that there would have been a net transport of matter out of the region, resulting in a decrease in pressure on that part of the earth's surface which was covered by the hemisphere before its expansion and an increase in pressure at points in an annulus surrounding the hemisphere. It is this pressure difference which caused the surrounding air to flow in and lift the air mass comprising the hemisphere.

In the above discussion of the rising F layer, one important factor has been neglected, namely, that electrons cannot readily move across the earth's magnetic field at F-layer heights. The tests were carried out at a location quite close to the geomagnetic equator, where the earth's field is horizontal, and at first sight it would appear impossible for a vertical motion of electrons to take place.

Chapman and Bartels[4] have demonstrated that the component of electron velocity perpendicular to a magnetic field is $\gamma^2/(\gamma^2 + \omega^2)$ times the velocity in the absence of the field, where γ is the collision frequency and ω is the angular gyrofrequency. At F-layer levels (250 km), this factor becomes 5.6×10^{-8}, and it is therefore obvious that the vertical velocity of electrons at the geomagnetic equator would be vanishingly small if no other mechanisms were involved. Actually, the place at which the tests were performed was not exactly at the geomagnetic equator, the magnetic dip at the blast site being approximately 13°. Therefore the vertical velocity would be greater than that obtained by multiplying the velocity in the absence of the earth's field by $\gamma^2/(\gamma^2 + \omega^2)$.

That this is the case may be demonstrated as follows:

Assume a rectangular coordinate system with the y axis horizontal and the x and z axes, respectively, perpendicular to and parallel to the earth's magnetic field, and let the inclina-

tion of the z axis to the horizontal be ϕ. If c_0 is the vertical velocity in the absence of the field, the components of c_0 perpendicular and parallel to H will be given by

$$c_\perp = c_0 \cos \phi \qquad c_\parallel = c_0 \sin \phi \tag{4.1}$$

Introducing the previously described factor of Chapman and Bartels, the x and z velocity components become

$$\dot{x} = c_\perp \frac{\gamma^2}{\gamma^2 + \omega^2} = c_0 \frac{\gamma^2}{\gamma^2 + \omega^2} \cos \phi \qquad \dot{z} = c_\parallel = c_0 \sin \phi \tag{4.2}$$

Projecting these components on the vertical direction, the vertical velocity in the presence of the earth's field is given by

$$w = \dot{x} \cos \phi + \dot{z} \sin \phi = c_0 \left(\frac{\gamma^2}{\gamma^2 + \omega^2} \cos^2 \phi + \sin^2 \phi \right) \tag{4.3}$$

For $\phi = 13°$, $\sin^2 \phi$ is 0.05, and the second term in the parentheses dominates at F-layer altitudes, since the coefficient of the first term is of the order of 10^{-7}. The velocity in the presence of the earth's field is, therefore, about $\frac{1}{20}$ of that which would exist in the absence of the field.

The vertical motion in the presence of the earth's field may be slightly enhanced by the phenomenon called "engulfing" by Hulburt,[5] who introduced it to explain the F-layer rise noticed during magnetic storms. Hulburt assumed that the rising air currents lift "short free path" air molecules to F-layer levels and that, after equilibrium is established, the mean free path of the F-layer electrons is reduced. This would be the equivalent of increasing the collision frequency γ and would result in an increase in the value of the first term in the above expression for the vertical velocity (Eq. 4.3).

4.2 TRAVELING DISTURBANCES

4.2.1 Observed Velocities and Quasi-periods

The F2-layer disturbance resulting from Mike shot had an indicated velocity of about 13 km/min (Chap. 3, Sec. 3.4.3). At Guam, the variations produced in the electron density had an apparent period of the order of 40 min (see Chap. 3, Sec. 3.4.5). Traveling disturbances having velocities and quasi-periods of the same order, apparently due to unknown natural causes, have been described by various observers during the last six years.

Munro[6] found velocities of 5 to 10 km/min, using a triangular system of ionosphere recorders. Bramley and Ross,[7] measuring the direction of arrival of nearly vertical wave trains, deduced effective tilts in the F2 layer progressing at velocities of 2 to 20 km/min. Somayajulu[8] found velocities of 12 to 18 km/min and Rao and Rao[8] reported a range from 9 to 15 km/min, using oblique propagation techniques. Price,[9] using a fixed frequency of 5.8 Mc and methods patterned after Munro, tabulated 318 moving disturbances, of which 52 per cent had velocities between 6 and 11 km/min and 91 per cent were in the range from 3 to 18 km/min.

The length of the quasi-period of these disturbances has not been communicated so fully, no doubt because of the greater difficulty of ascertaining it and the fact that the larger disturbances frequently consist of only one complete cycle of oscillation. Munro,[6] however, reported a range of 10 min to 1 hr. Values of 25 to 30 min have been generally accepted as typical by Hines,[10] Martyn,[11] and Mitra.[12]

4.2.2 Theoretical Treatments

Several authors have made theoretical investigations of the propagation of traveling disturbances in the ionosphere, attempting no explanation of their presumably natural origin. The phenomenon has been treated both as if it were a magneto-hydrodynamic wave and as a cellular wave.

In a study of sunspots, Alfven[13] demonstrated the existence of magneto-hydrodynamic waves, produced when a conducting fluid embedded in a magnetic field is displaced in a direction perpendicular to the field. This theory was extended by Hines,[14] who later applied it to the ionosphere in an interpretation of moving irregularities.[10]

Martyn[11] ascribed these ionospheric disturbances to cellular atmospheric waves horizontally propagated at ionospheric levels. According to his explanation, charged particles, impelled by the moving neutral air but constrained to move along lines of force in the earth's magnetic field, become so redistributed as to cause the observed variations in electron density. He noted that such cellular waves are rotational in type and require both an upper and a lower boundary. Whereas a lower boundary might easily exist in the vicinity of 80 km owing to the sudden change in the temperature lapse rate, an upper boundary was shown to require either a region of high lapse rate (believed to be unacceptable at F2 levels) or a value of γ (the ratio of specific heats) much closer to 1.0 than the accepted value of 1.4. He believes that such a low value for γ is possible at a level where nitrogen begins to dissociate.

The effect of the earth's magnetic field, in the case under consideration by Martyn (60° inclination), is to move electrons upward in one part of the rotating cell and downward in another, both along the lines of force. Although this vertical movement would not be so great near the geomagnetic equator, there would be a horizontal displacement of electrons which would result in an effectively tilted layer. The passage of the disturbance would thus be observable by radio means at the low geomagnetic latitudes relevant to this experiment.

4.2.3 Possible Origin

A large amount of the energy contained in the shock wave resulting from Mike shot was probably dissipated as heat high in the ionosphere. (This is expected from theoretical considerations and was indicated by the observations, at Bikini, of the formation of new E and F1 layers below the rising F2 layer, discussed in Chap. 3, Sec. 3.1.2.) If part of this ionospheric region was heated to such an extent that a superadiabatic lapse rate existed above it, the resulting unstable condition might easily have led to vertical eddies. Such eddies would tend to involve the adjacent air and might have been the initiating cause of the type of cellular disturbance described by Martyn.[11]

It should also be mentioned that the sudden heating of a large volume of the upper atmosphere has been considered sufficient cause for the setting up of new oscillations, of quite long period, confined to regions above the ozonosphere. (See Sec. 3.5 of the report of Project 9.4, Operation Snapper.[3])

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CHAPTER 5

CONCLUSIONS

5.1 DIRECT IONOSPHERIC EFFECTS OF THE BLAST WAVE

The presence of abnormally reflected, refracted, and scattered radio signals indicates that the effect of the explosions on the ionosphere was similar to that occurring during previous nuclear tests. Although the geometry was somewhat different, detailed analysis corroborated the conclusion given in the Snapper report[1] that the radio propagation effects can be attributed to local increases in ion density occurring at the time of passage of the blast wave.

5.2 INDIRECT IONOSPHERIC EFFECTS OF THE BLAST WAVE

A new phenomenon, consisting of a protracted and relatively slow rise of the F2 layer that began just after the expected arrival of the blast wave resulting from the larger shot, can probably be ascribed to the heating effect of the shock wave. Since it was not observed following the smaller shot, the minimum energy release required to produce this phenomenon is apparently greater than half a megaton.

5.3 INTERFERENCE TO IONOSPHERIC RADIO COMMUNICATION

No major disturbance to ionospheric communication appears likely to result even from the detonation of very powerful weapons. The attenuation which was observed for all radio waves passing through the lower ionospheric regions in the vicinity of the large nuclear explosions was not sufficient to reduce the signal strength below a level that might occur during normal ionospheric absorption. The duration of decreased signal intensity was short, being of the order of 15 min. Furthermore, since any ionospheric radio propagation path terminating in the vicinity of a nuclear explosion would intersect the blast wave in the lower ionosphere at a point far from GZ, communication with the source area would not be affected until the blast wave reached that distant point (up to 35 min, depending on the location of the remote station).

5.4 DISTANT EFFECTS

An unexpected phenomenon revealed by this experiment is the initiation of a traveling disturbance in the ionosphere by a sufficiently large explosion. The observed propagation of this disturbance to a distance of at least 1900 km (possibly as much as 4500 km) at a velocity of the same order as found for naturally caused moving irregularities and with a similar quasi-period is, in itself, of great interest in the study of the ionosphere. In addition, it might prove useful as a corroborative means of long-range detection of large nuclear detonations.

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CHAPTER 6

RECOMMENDATIONS

6.1 FUTURE OPERATIONS

Since ionospheric measurements made in connection with nuclear tests have proved to yield valuable data in the furtherance of an understanding of the ionosphere, and since such detonations provide an energy source of known time and location which cannot be duplicated by other means, it is recommended that similar experiments be performed during future operations of this nature. In particular, confirmation should be sought, by experimental participation in Operation Castle, for the association of both the slowly rising F2 layer and the distantly propagated F2-layer disturbance with explosions of megaton order. If the rising F2-layer phenomenon is again observed, further study should be made of the formation of the new normal F2 layer to determine the process involved. In order to obtain a better insight into the mechanism of the rising F2 layer, two ionosphere recorders, at different distances and in different directions, should be operated in the general vicinity of the detonations. Frequent data should also be obtained at as many existing distant locations as possible in order to attempt detection of traveling disturbances initiated by the detonations.

6.2 LONG-RANGE DETECTION

The possibility of the use of data from existing ionosphere stations to corroborate other means of long-range detection of large nuclear explosions should be considered.

6.3 DECLASSIFICATION

If use of the propagated disturbance in the ionosphere for long-range detection is not contemplated and if there are no other apparent military uses, it is suggested that the information and data concerning the observed traveling disturbance be declassified in order to permit their dissemination among physicists throughout the world who are studying moving irregularities in the F2 region as part of the effort to determine ionospheric characteristics.

6.4 ADDITIONAL DATA

Ionospheric records taken at the many existing stations throughout the Pacific area should be examined for evidence of the traveling disturbance initiated by Mike shot in order to check whether or not the effect, indicated as possibly observable at Maui and Okinawa, can actually be found at such great distances and, if so, whether or not the occurrence or velocity exhibits any directional characteristics. (There are stations at Adak, Alaska; at four locations in Japan; at Townsville and Brisbane, Australia; at Rarotonga, Cook Islands; and at San Francisco, Calif.)

APPENDIX A

OPERATOR'S REPORT (IONOSPHERE RECORDER)

TEST MIKE

The equipment was put into normal operation (i.e., one $7\frac{1}{2}$-sec sweep every quarter hour plus one sweep at 1 min past the hour) at 1200 hours (local time) on 23 October and maintained intermittently until 0700 hours on 1 November, at which time it was shut off to prevent interference with the multichannel equipment. H hour was approximately 0715 hours. The equipment was then operated on $7\frac{1}{2}$-sec sweep in the following manner:

a. 0719–0852, continuous duty
b. 0852–1205, one sweep per minute
c. 1205–1445, one sweep every 5 min
d. 1445–5 November, normal operation

The records were developed and scaled.

TEST KING

The equipment was put into normal operation (i.e., one $7\frac{1}{2}$-sec sweep every quarter hour plus one sweep at 1 min past the hour) at approximately 0900 hours (local time) on 11 November and maintained continuously until 1115 hours on 16 November, at which time it was shut off to prevent interference with the multichannel equipment. H hour was approximately 1130 hours. The equipment was then operated on $7\frac{1}{2}$-sec sweep in the following manner:

a. 1134–1234, continuous duty
b. 1234–1430, one sweep per minute
c. 1430–1500, on 16 November, normal operation

The equipment was then shut off. All records were developed and scaled, and the antenna was down by 2100 on 19 November. The trailer was packed and secured for shipment at 1030 on 20 November.

/s/ Julian E. Wakefield, Jr.
Acting Corporal

APPENDIX B

OPERATOR'S REPORT (C-W TRANSMISSION)

TEST MIKE

1. Plane departed Kwajalein Island at 0158M, 1 November 1952, and proceeded to point 11° 42' North and 158°57' East. Contact was attempted with station 8FT on Bikini beginning at 0300M on the frequencies assigned: 3302.5, 5600, and 9422.5 kc. Two-way communication with 8FT was unsuccessful up to 0645M. At that time it was decided to send blind on 5600 kc. The plane began flying a clockwise ellipse, north to south, with the straightaway distance being approximately 12 miles. The plane, Navy designation P2V, No. One, was piloted by CDR Berg, Commanding Officer of VP-2 Unit, Kwajalein, and flown at an altitude of 1100 ft during the entire test. Radio call sign of the plane was 1Z34. The transmitter, type ART-13, was operating at 90 watts input with 2.4 rf amp into a 52-ft fixed antenna.

2. The 5600-kc signal was keyed as follows:
   a. Two 1-sec breaks going in and two 1-sec breaks coming out of south turn.
   b. One 1-sec break going in and one 1-sec break coming out of north turn.

3. The transmitter was keyed at following intervals:

South	North
0643–0644	0647–0648
0652–0654	0659–0700
0705–0706	0712–0713
0717–0720	0724–0725
0730–0731	0735–0737
0740–0741	0745–0746
0751–0752	0756–0757
0802–0803	0808–0809
0813–0814	0819–0820
0824–0826	0830–0832
0835–0837	0842–0844
0847–0848	0852–0853
0859–0900	0904–0905
0909–0911	

All times shown are in M (local) time.

4. Station 8FT, Bikini, was contacted at 0932 verifying reception. The shot was observed at 0715, the shock wave reaching the aircraft at 0729. Test was secured at 0915, and plane performed patrol operations, landing on Kwajalein Island at approximately 1240.

TEST KING

1. Plane left Eniwetok 0822, 16 November 1952, and proceeded to a point 11°42' North and 158°57' East, arriving on station at 0920. The plane then began flying a clockwise ellipse, north

to south, the straightaway distance being approximately 13 land miles. The plane, Navy designation P2V, No. Three, was piloted by Lt Beasley, Patrol Squadron Two, Kwajalein Island.

2. Contact was made with 8FT. Bikini Atoll, at 1035, and pretest checks were made. Radio call of the plane was 3Z34. Test operation began at 1100 hours on 5600 kc. The ART-13 transmitter was operating with 95 watts input and 1.5 rf amp into a 125-ft trailing wire antenna. The plane maintained 1000-ft elevation throughout the test.

3. The transmitter was keyed as follows:

Going into south turn	- One 1-sec break
Leaving south turn	- One 1-sec break
Going into north turn	- Two 1-sec breaks
Leaving north turn	- Two 1-sec breaks

Above is reversed from "M" test, 1 November 1952. Breaks were timed as follows:

North End	South End
1100–1101	1106–1107
1112–1113	1117–1118
1123–1124	1128–1129
1132–1133	1137–1139
1143–1144	1148–1150
1154–1155	1159–1201
1205–1206	1210–1211
1216–1217	1221–1222
1227–1228	1232–1234
1238–1239	1242–1243
1245–1246	1251–1252
1256–1257	1301–1303
1307–1308	1312–1313
1318–1319	1322–1324
1328–1330	

All times are in M (local). The shot was not observed. Test was secured at 1330, and plane assumed patrol duty, returning to Kwajalein at 1655.

/s/ Pvt Richard W. Stroud

APPENDIX C

OPERATOR'S REPORT (C-W RECEPTION)

TEST MIKE

1. On 1 November 1953 a watch was kept on the assigned frequencies from H−3 hr, and at H−3 min a strong carrier was heard on 5600 kc. On the chance that it was the plane, the equipment was turned on and a record was taken. At H+2 hr contact was made, and the test was confirmed. A strong signal of S7 was recorded until H+10 min when the signal dropped suddenly and remained at a low point until H+22 min when it started gradually rising. During the rest of the record no extraordinary changes were noted, and the record was stopped at H+2 hr 22 min (9:27 A.M. local Marshall Islands time). Time is recorded on the chart by 1-min marks in the left-hand margin and H, H+30 min, H+1 hr, H+1 hr 30 min, and H+2 hr are marked in blue ink. This was done after the recording on the basis of stopping the record at 9:27 A.M.

2. The control settings on the receiver and the d-c amplifier were as follows:

RF GAIN	Maximum	D-C AMPLIFIER	As marked
BFO	On	SIGNAL AT ZERO BEAT	
AUDIO GAIN	Irrelevant	AVC	On
LIMITER	Zero	BFO PITCH	Zero
BAND PASS	Zero		

The antenna was a half-wave doublet center fed with 72-ohm coaxial cable, resonant to 5600 kc and having a bearing of 270°. It was 40 ft above the ground.

3. As no signal generator was available to calibrate the Esterline-Angus recorder, a calibration chart was made using the BC 610 transmitter exciter stages and the S meter on the BC 779 receiver. The curve was run using S-meter readings of S9, 8, 7, 6, 5, 4, 3, 2, and 1, with the Esterline-Angus recorder reflecting the changes. These readings are printed on the calibration chart alongside of the curve.

TEST KING

1. On 16 November 1952 contact was made prior to the test, and the test was begun at H−30 min. A signal strength of S7 was recorded until a few minutes after the shot, when it dropped and never did recover in strength completely. The noise level was very high, running between S2 and S3. An interfering signal was recorded near the end of the test and marked in blue ink to the right of the pip it caused. When the signal dropped in strength, the gain of the d-c amplifier was changed to full gain, and, when the signal apparently came up again, it was reduced to the original value. It was not necessary to increase it again after this as the signal strength fell to a value equal to and less than noise level. Time is recorded on the chart by marks in the left-hand margin at 15-min intervals.

(Paragraphs 2 and 3 the same as for Test Mike above.)

/s/ Charles H. Bowen
Pvt-2

APPENDIX D

OPERATOR'S REPORT (TELETYPE)

TEST MIKE

1. On 31 October 1952 we attempted to copy RTTY signals from Guam to Kwajalein from H−25 to H−20 hr on 8935, 12,940, and 17,470 kc. Found nothing on or near any of these frequencies. Attempted to copy the Guam-to-Honolulu circuit on 7810, 11,610, 15,554, and 20,772 kc during the same time. Results were also negative.

2. On 1 November 1952 we repeated the same procedure used on 31 October 1952. At H−30 min RYRYRYRY test tape was found on 7810 kc. The call sign identified it as "AID CONTROL," which is unknown to me. I decided to copy same in the hope that it might be of some value rather than nothing at all. Began recording at H−30 min and continued uninterrupted until H+19 min when it was necessary to acknowledge the URGENT call from "ABSTAIN," the oceanography ship. Was again interrupted at H+30 min to acknowledge another URGENT call from "ABSTAIN." Continued recording until it was necessary to acknowledge plane-to-ground signals at H+2 hr 10 min. At H+2 hr 20 min "AID CONTROL" quit sending. Tried once again to monitor Guam-to-Kwajalein or Guam-to-Honolulu circuits without success. From H+47 to H+54 min tried to monitor an RTTY signal on 12,940 kc. A signal was present around 12,960 kc but was not printable, and signal strength was well below noise level; so returned to 7810 kc until they quit sending.

3. On 2 November 1952 we tried the same procedure as 31 October 1952 but had nothing readable.

4. Records were taken using the optimum control settings on the receivers as follows:

BFO	Off
RF GAIN	On full
AF GAIN	Out
AVC	On
LIMITER	Out

Dual diversity converter settings were as follows:

FREQUENCY DRIFT COMPENSATOR	Out
NARROW/WIDE BAND PASS FILTER	Narrow
L.P. FILTER	In

Two doublet antennas were used. Resonant to 8935 kc, center fed and elevated 40 ft above the ground; 72-ohm coaxial cable was used for lead-in. Antennas were spaced one behind the other, approximately 60 ft and bearing 270°. Antennas should have been spaced further apart to provide best dual diversity reception, but this was impossible due to lack of time to clear the area.

TEST KING

1. On 16 November 1952, in accordance with changes received in a letter dated 6 November 1952 from the 9.2 Project Officer to Captain Giroux, the Eniwetok circuit was to be monitored instead of the Guam-to-Kwajalein RTTY circuit. The Eniwetok circuit could not be heard; however, on 9947 kc (only 3 kc from the Eniwetok frequency) we picked up a strong RTTY signal identified as DZM25, that we believed to be located in Manila, P.I. Since no RTTY signals were received at 9950 kc, we monitored DZM25 from H−30 min to H+2 hr 45 min, at which time the signal went off after having indicated that they were changing frequency. No records were obtained from DZM25 or ABE at Eniwetok on 15 November 1952 or 17 November 1952. On 17 November 1952, while copying ABE at Eniwetok on 9950 kc, the signal from DZM25 could be heard in the background, but no records were taken because of the stronger signal from ABE at Eniwetok.

(Paragraph 2 for Test King the same as paragraph 4 for Test Mike above.)

/s/ Allen C. Linder
Corporal

End
filmed
12-65